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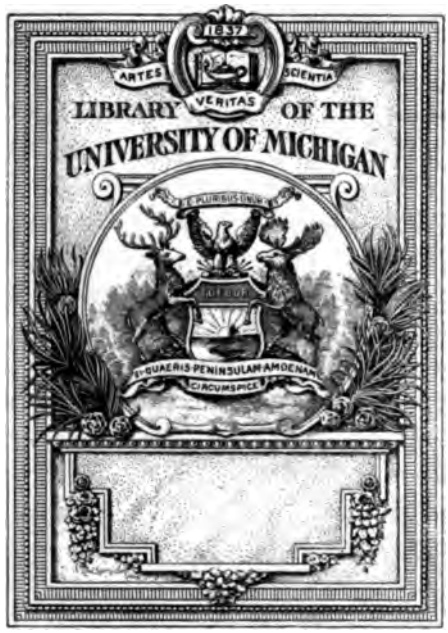
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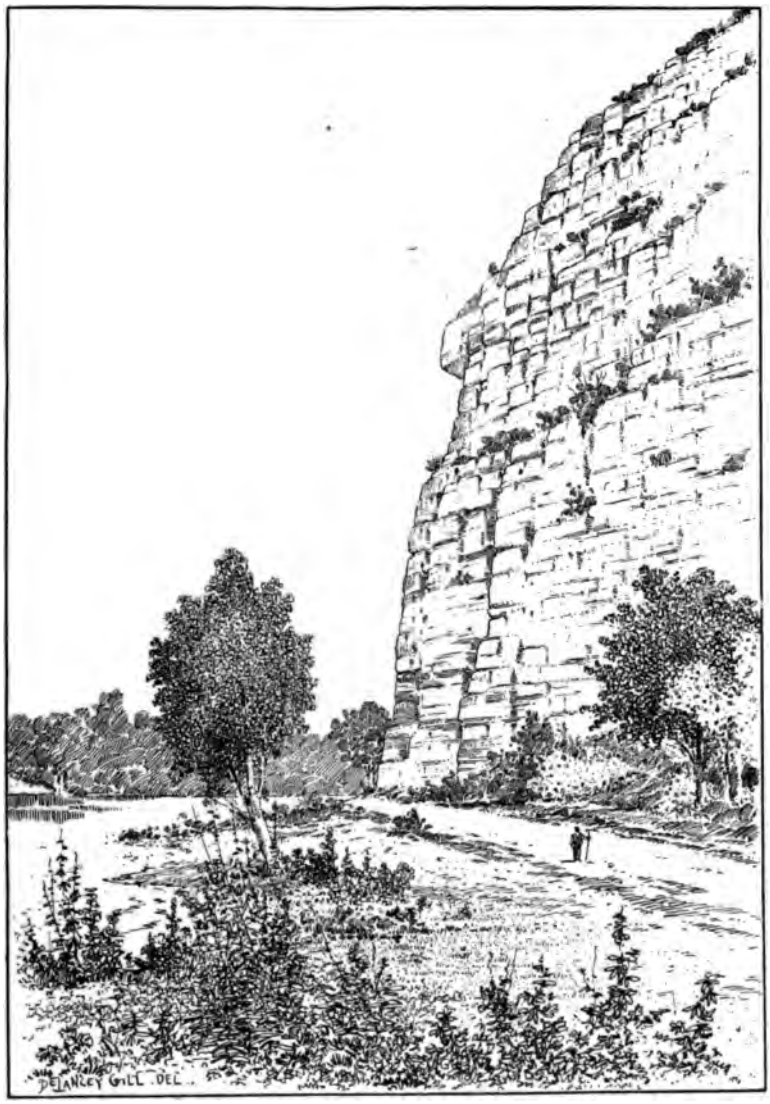

PENTER'S BLUFF ON THE WHITE RIVER, BATESVILLE REGION, ARKANSAS.

ANNUAL REPORT

OF THE

GEOLOGICAL SURVEY

OF

ARKANSAS

FOR 1890

VOLUME I

MANGANESE: ITS USES, ORES, AND DEPOSITS

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OFFICE OF THE GEOLOGICAL SURVEY OF ARKANSAS,
LITTLE ROCK, Feb. 6th, 1891.

To His Excellency,

Hon. James P. Eagle,

Governor of Arkansas.

Sir:

I have the honor to submit herewith Volume I. of my annual report for 1890, and to remain,

Your obedient servant,

JOHN C. BRANNER,

State Geologist

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PREFACE.

The Geological Survey's work upon manganese was taken up in July, 1889, and entrusted to Dr. R. A. F. Penrose, Jr., assistant geologist, by whom all the work has been done except such aid as could be given by others in mapping, drawing, and in making analyses. Every known manganese mine and locality in the state has been examined by him, and is here reported on in its general geologic relations and almost always in detail.

Besides describing occurrence of ores in this state, the subject of manganese has been taken up as a whole. This has led to an investigation of the different kinds of ore and of the uses to which they are put. In order to ascertain the importance of the Arkansas deposits, it was necessary to know to what extent the other mines in the country could meet the demand for manganese. This made it essential that all the other manganese mines should be examined. But as the funds appropriated were not available for work outside the state, Dr. Penrose has himself met these expenses out of his private funds, and, in addition to doing the field work on manganese in this state, he has visited and personally examined every known manganese region in North America—those of Georgia, Tennessee, Virginia, Vermont, Texas, Arizona, Colorado, California, Oregon, Nevada, Utah, Nova Scotia, and New Brunswick; only lack of time prevented his visiting those of Cuba and Chili. The conclusions given in the report are therefore based upon direct personal observations, and it is felt that they are thoroughly trustworthy. The descriptions of deposits other

than those of Arkansas serve to bring out in bolder relief the value of our manganese ores.

The report has been prepared upon the general plan of discussing:

1. The uses of manganese, together with the history and statistics of the manganese industry;
2. The ores of manganese;
3. The nature of the manganese deposits.

In the descriptions of localities the deposits of the Batesville region have been treated first, and in greater detail than the others, for not only did those deposits furnish the chief incentive for making the present investigation, but they have been worked up more thoroughly than the other regions, and their discussion forms the most important part of the report. After the discussion of the Arkansas deposits, the Appalachian region is described; then the various other localities are taken up geographically, beginning with Texas and continuing westward to California; the deposits of Canada are treated last.

The small map showing the distribution of manganese in the United States and Canada gives the principal areas from which ore has been shipped, and those from which, either on account of its scarcity, poor quality, or distance from railway transportation, no important quantities of ore have yet been produced. The distinction between these two classes of localities is, in certain cases, somewhat arbitrary, but the classification has been made on the basis of the best statistical information obtainable. (See chapter IV.)

A geological map of the Batesville region is folded in the pocket in the cover of the volume. The geographic base of this map was compiled from the government township sheets, and these were corrected and added to by data collected by the Survey. Later a number of roads were added from the field sheets of the U. S. Geological Survey topographic corps by whom the region was mapped after the present State Survey had finished the geologic work. The topography of the Boston Mountains is from the

same source. No attempt is made to show the topography in the region north of the Boston Mountains, for its representation would obscure important geologic details.

Dr. Penrose was aided in the preparation of the map of the Batesville region by Prof. J. H. Stoller, T. C. Hopkins, Prof. W. S. Blatchley, D. M. Barringer, and H. Landes. In southwestern Arkansas the geologic investigations made by Mr. L. S. Griswold of the novaculites aided materially in the comprehension of the details of the structural geology and distribution of the manganese-bearing strata in that part of the state.

The chemical analyses when not otherwise accredited have, with the exception of that of pelagite (p. 83) which is quoted from J. D. Dana, been made in the chemical laboratory of the Survey by Dr. R. N. Brackett.

Two classes of analyses, mineralogical and commercial, are given. The mineralogical analyses are of carefully selected specimens of the purest and most characteristic ores from each region. They are intended to show the mineralogical nature of the ores and do not represent their economic value in large quantities. The commercial analyses are made of samples taken from large shipments of ore in the condition in which it is used, and are intended to represent the commercial values of the ores. A number of these analyses are given with most of the important manganese localities. In cases where such analyses were not obtainable, however, analyses of hand samples are given. Where the ores are useful mainly for the manufacture of spiegeleisen and ferromanganese, the commercial analyses represent the contents of the ores in manganese, iron, silica, and phosphorus. Where the ores have an additional value for oxidizing purposes, such as the manufacture of chlorine, etc., the amount of peroxide of manganese is also given.

The measurements of elevation given in the report were made, unless otherwise stated, with an aneroid barometer.

The want of adequate library facilities has made it

impossible to give with this volume a complete bibliography of manganese, but with the exception of half a dozen of the less important ones all the titles known to the author are given in the foot notes.

Aside from the aid acknowledged in the body of the report and in the preceding part of this preface, the work represented by this volume, from the collection of data in the field to the reading of proof, has all been done by Dr. Penrose in person. His unwearying industry and zeal, his enthusiastic absorption in and devotion to the work cannot be too highly praised, while his intelligent grasp of the subject and his clear treatment of it cannot fail of appreciation by geologists and by all who are interested in manganese.

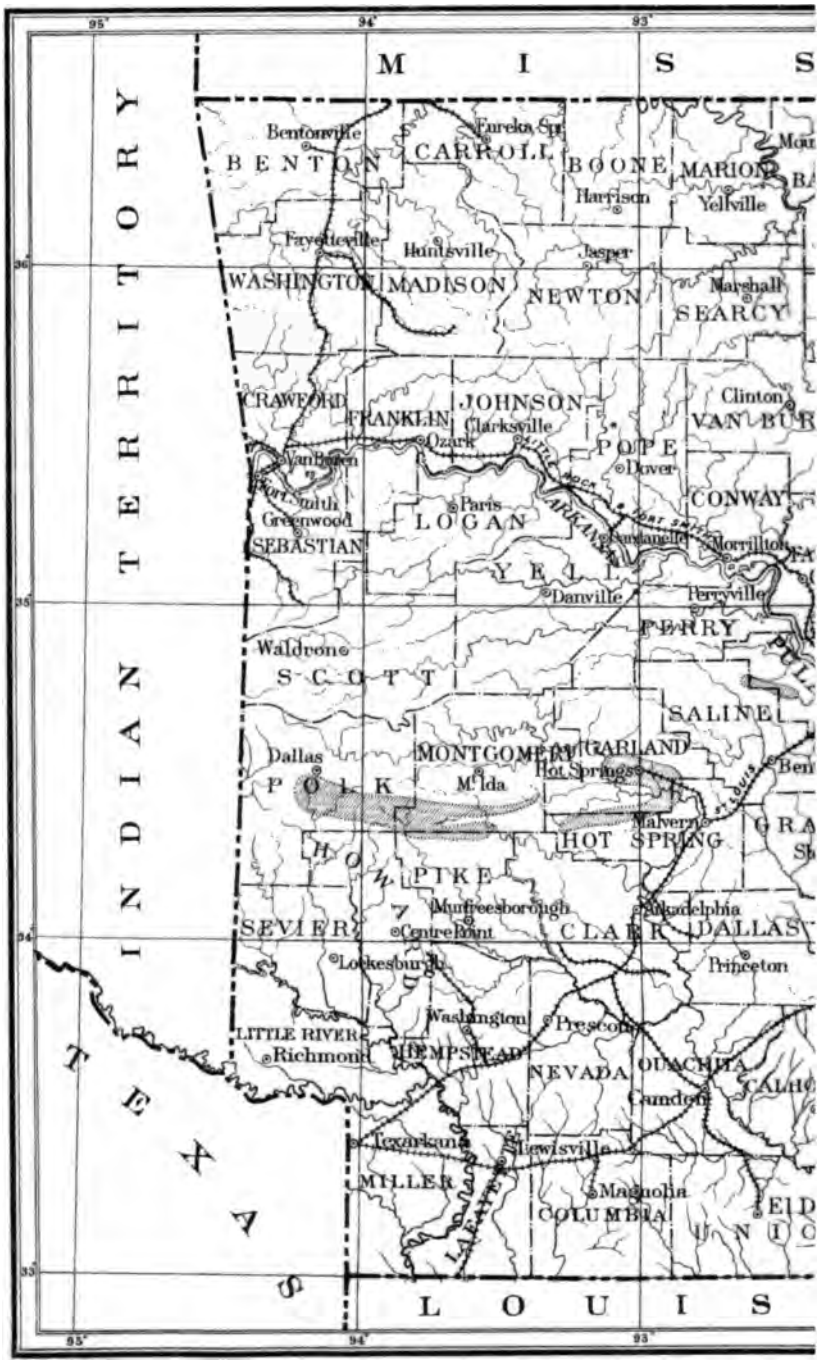
It is hoped that professional readers will bear in mind, however, that the writer of a state geological report must often sacrifice brevity and conciseness for the sake of making his meaning plain to the unprofessional. On the other hand the unprofessional reader should remember that it is impossible to dispense entirely with technicalities in discussing a technical subject.

The Survey is indebted to so many persons for kind aid in this work that it is impossible to mention them all. In the manganese region of this state the Survey has met with uniform cordiality and kindness. Especial acknowledgements are due Dr. J. E. Wolff of Harvard University for microscopic examinations of rocks, and to Dr. S. L. Penfield of Yale University for assistance on the mineralogy of certain of the manganese minerals; Mr. James E. Mills of San Francisco has given the Survey the benefit of very valuable suggestions and observations; Mr. E. Gilpin, Jr., Commissioner of Mines for Nova Scotia, has kindly furnished valuable statistics and other information regarding the deposits of that province; Major A. Markham of Markhamville, N. B., and Major W. K. Armistead of Abingdon, Va., aided very materially by their cordial assistance and information regarding their respective regions.

The studies made by the Survey lead to the conclusion

that the southwestern manganese areas of Arkansas, namely, Polk, Montgomery, and Pulaski counties, formerly supposed to be rich in manganese, contain no deposits of value. This is not gratifying, but it is conclusive, and must be so accepted. It is very gratifying, however, to know that these same studies show that the Batesville region is one of the most important manganese fields known in North America.

JOHN C. BRANNER,
State Geologist.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Huntsville
Jasper
WASHINGTON
MADISON
NEWTON
Marshall
SEARCY
CRAWFORD
FRANKLIN
JOHNSON
Clarksville
Ozark
POPE
Clinton
VAN BUR
Dover
Van Buren
Fort Smith
Paris
LOGAN
CONWAY
Greenwood
SEBASTIAN
Danville
Perryville
YELL
PERRY
Waldron
SCOTT
SALINE
Dallas
POLK
MONTGOMERY
GARLAND
Hot Springs
Mena
Malvern
HOT SPRING
PIKE
Murfreesborough
Arkadelphia
SEVIER
Centre Point
CLARK
DALLAS
Lockesburg
Princeton
Washington
Prescott
LITTLE RIVER
Richmond
HEMPSTEAD
NEVADA
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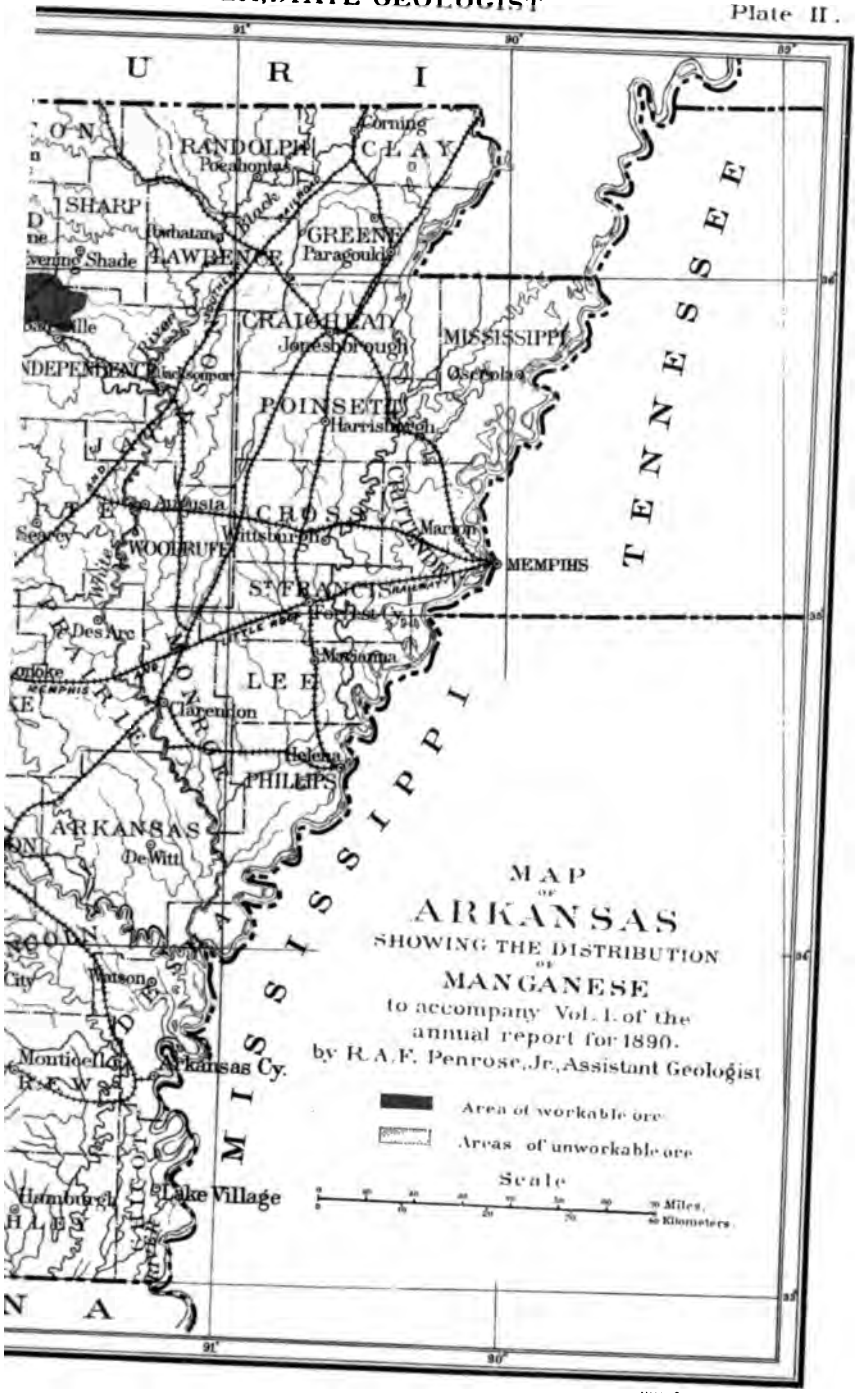
Camden
Texarkana
Lewisville
MILLER
Magnolia
COLUMBIA
RED
Arkansas
Red
Ouachita
Little Missouri



JULIUS BIEN & CO. LITH

MANGANESE

ITS USES, ORES, AND DEPOSITS.

By R. A. F. PENROSE, JR., Assistant Geologist.

CHAPTER I.

NATURE AND EARLY USES OF MANGANESE.

Nature of manganese.—Manganese is a metal and represents one of the elementary substances composing the earth's crust. It belongs to what is known as the iron group, which comprises iron, manganese, cobalt, and nickel. These metals form compounds which, in their chemical relations, have certain points of similarity to each other, and they are therefore classed together. They are frequently associated with each other in nature; and, in fact, one of the most common modes of occurrence of manganese ore is with iron ore deposits.

Manganese in the mineral kingdom.—Manganese is never found in the metallic state in nature, but is always in combination with one or more of the other elementary substances, and generally occurs as oxide, silicate, or carbonate. In these forms, it is one of the most widely distributed of the metals in the mineral

kingdom, and is almost coextensive with iron, though in very much smaller quantities. It is an essential constituent of many minerals, and is found in greater or less quantities in almost all metamorphic, eruptive, and sedimentary rocks. It also represents one of the twenty-two or more elementary substances found in meteorites. The oxides are the most common manganese minerals, but the simple silicate and carbonate, known respectively as rhodonite and rodochrosite, are also of frequent occurrence; while garnet, pyroxene, and amphibole, as well as many other minerals, frequently contain manganese. Rhodonite is often cut for jewels on account of its beautiful pink color, and the purple of the amethyst is supposed to be due to the presence of manganese. Only a few of the minerals containing manganese, however, are available as ores of the metal, and those which can be used are only rarely found in sufficient quantities and of such quality as to be of commercial value.

Manganese in the animal and vegetable kingdoms.—Though manganese in large quantities is confined to the mineral kingdom, it is widely distributed in minute quantities in both the animal and vegetable kingdoms. It is said to form an essential constituent of the tissues and of the red corpuscles of the blood in the human body, being present in the proportion of one part of manganese to twenty parts of iron. In the vegetable kingdom it enters into the composition of many plants: E. N. Horsford* has found manganese in the ash of some varieties of tea, coffee, potato, and squash; and E. Maumené† describes its existence in tobacco, potatoes, beets, carrots, grapes, apricots, wheat, rye, rice, and many other vegetables, fruits, and cereals. It is by means of such materials that manganese enters into the animal kingdom; and, in fact, the general distribution of manganese in animal and vegetable organisms, though in small quantities, is directly traceable to its persistent presence in soils, where it has been derived from the decay of rocks. It is absorbed from the soil by plants, and transmitted thence to animal blood and tissue.

Manganese represents one of the mineral constituents

* Amer. Jour. Sci., 2d. series, Vol. XI., 1851, p. 259.

† Comptes rendus de l'Acad. des sci., t. XCVIII., 1884, pp. 1416-1419. For the existence of manganese in wines see E. Maumené, Ibid., pp. 845-846 and 1056-1058.

of many trees, being found in the ash of certain forms of the oak (*Quercus robur*), the chestnut (*Castanea vesca*), and the floating plant known as *Trapa natans*.* It also occurs in several species of the genus *Cinchona*,† the source of the commercial quinine.

Ancient and medieval uses and names of manganese.—The application of manganese in the arts is of great antiquity, and dates back at least as far as the times of the ancient Egyptians. One of its first uses was in glass-making, and analyses of Egyptian and Roman glassware have shown the presence of over two per cent of the protoxide of manganese,‡ equal to over one and a half per cent of metallic manganese.

Pliny, in his treatise on natural history, mentions the use of manganese oxide among the Romans in decolorizing glass. He considered it a variety of magnetic iron ore, or lodestone, which he speaks of as *magnes*. During the middle ages it was known as *magnesia*, and was later referred to as *magnesia nigra*, in distinction from the true magnesia, or *magnesia alba*. The name manganese is of somewhat obscure origin. It is supposed by some to have been derived from the expression *magnesia nigra*, by metathesis. It appears in such expressions as *lapis manganensis* in the Latin literature of the 16th century,‖ and still later as *manganesium*, but as late as the 18th century it was frequently mentioned as *magnesia nigra*. These names all referred to the oxide of manganese, since the metal was not known until the latter part of the last century.

Growth of knowledge concerning manganese.—Though the oxide of manganese and its more apparent properties were known to the ancients, and to the priests and chemists of the middle ages, yet the old idea of Pliny, that it was a form of iron ore, was still generally retained until late in the last century. Glauber carried on experiments with the compounds of manganese about the middle of the 17th century, and in his work known as The Prosperity of Germany, published in 1656, he describes his investigations.

*Gray's Botanical Text Book, Vol. II., Geo. L. Goodale, Physiological Botany, p. 256.

† E. Maumené, Comptes rendus de l'Acad. des sci., t. XCIII., 1884, p. 1417.

‡ R. A. Hadfield, Proceed. Civil Engineers, XCIII., 1888, III., p. 59.

‖ Roscoe and Schorlemmer, Treatise on Chemistry, Vol. II., Pt. II., p. 2.

In 1740, Potts* showed that oxide of manganese formed a series of salts distinct from those of iron, but the existence of a separate metal was not understood, and even as late as 1758 Cronstedt† speaks of it as a "kind of earth" with "no greater quantity of metal than sometimes two or three per cent of iron and sometimes a little tin."

Scheele's celebrated experiments,‡ published in 1774, mark the first systematic attempt to investigate manganese and its compounds, and to his labors are due the first detailed knowledge of the subject. He suspected the existence of a metal in the magnesia nigra, but was unable to isolate it. This was accomplished shortly afterwards (1776), for the first time, by Dr. Gahn; though Kaim of Vienna is quoted as stating, in 1770, that a "peculiar metal" could be extracted from oxide of manganese.

Hence it will be seen that, though certain uses of oxide of manganese have been known from ancient times, our knowledge of the nature of the metal itself is of modern date, and on this knowledge are based the most important of its present applications in the arts. Its principal commercial use up to the end of the last century, seems to have been in decolorizing glass, as well as in coloring both it and pottery, as explained in chapter III. Considerable quantities, obtained from the Mendip-Hills, near Bath in England, are said to have been used in the last century by the Bristol potters, among whom it was known as "glassmaker's manganese," "glassmaker's soap," or "black glass." It was not until 1785, however, after Berthollet had suggested the economic application of chlorine in the arts, and works for its manufacture had been started at Javelle, in France, that an extensive field for the application of manganese arose. Manganese ore was a necessary reagent in the manufacture of chlorine and the demand for it soon rapidly increased. In 1786 chlorine works were started in England by James Watt, and in

* Examen Chymicum magnesia vitrariorum, Germanis Braunstein. (Roscoe and Schorlemmer.)

† Alex. Frederic Cronstedt, An Essay towards a System of Mineralogy, translated from the Swedish by Gustav von Engstrom in 1788, p. 849.

‡ Stockholm Memoirs, 1774, (Handlingar Kongl. Svenska vetenskaps Akademien (?))

1799 Charles Tennant erected the celebrated St. Rollox works at Glasgow.

With the introduction of manganese in the manufacture of steel by Heath, in 1839, and the subsequent immense increase in the production of steel by the invention of the Bessemer process less than twenty years later, another great use for manganese was found, and at the present day this use has become such an important factor in the metallurgy of steel, that it probably consumes over nine-tenths of the manganese production of the world. The demand for manganese in the manufacture of chlorine has decreased considerably since the introduction of the Weldon regenerative process, which makes it possible to use the same ore over again indefinitely.

Besides these two main uses of manganese, numerous other minor sources of consumption have arisen (see chapter II.) and even yet the ancient Egyptian and Roman practice of using it in glass consumes certain quantities.

CHAPTER II.

MODERN USES OF MANGANESE.

CLASSIFICATION OF THE USES OF MANGANESE.

Manganese is used at the present day for a great many different purposes in the arts; but, as already stated, probably over nine-tenths of the manganese ore produced is consumed in the manufacture of the alloys of iron and manganese, known as spiegeleisen and ferro-manganese, which in turn, are used in the manufacture of steel. If the class of manganiferous iron ores were included as manganese ores, the proportion consumed for these purposes would be vastly greater. Smaller quantities of manganese are used in manganese-bronze, silver-bronze, and other alloys. Next to its application in alloys, its most important use, when in the form of pyrolusite (peroxide of manganese), is as an oxidizer in the manufacture of chlorine. No chlorine, however, is made in the United States, all that is used in this country being imported. Smaller quantities of manganese are also consumed for many other industrial purposes.

The various uses to which manganese and its compounds are put, may be divided into three classes: alloys, oxidizers, and coloring materials. Each of these classes includes the application of manganese in sundry manufactured products, or as a reagent in carrying on different metallurgical and chemical processes. The most important of these sources of consumption may be summarized as follows:

*Uses of manganese.**

- **ALLOYS**
  - Spiegeleisen — Alloys of manganese and iron.
  - Ferro-manganese — Alloys of manganese and iron.
  - Manganese-bronze — Alloys of manganese and copper with or without iron.
  - Silver-bronze — An alloy of manganese, aluminum, zinc, and copper, with a certain quantity of silicon.
  - Alloys of manganese with aluminum, zinc, tin, lead, magnesium, etc.
- **OXIDIZERS**
  - Manufacture of chlorine.
  - Manufacture of bromine.
  - As a decolorizer of glass (also for coloring glass, see coloring materials).
  - As a dryer in varnishes and paints.
  - Leclanché's battery.
  - Preparation of oxygen on a small scale.
  - Manufacture of disinfectants (manganates and permanganates).
- **COLORING MATERIALS**
  - Calico-printing and dyeing.
  - Coloring glass, pottery, and brick.
  - Paints — Green. Violet.

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* Besides these main uses of manganese a certain amount is consumed as a flux in smelting silver ores, a purpose to which iron ore is also extensively applied. Many silver ores, especially in the western states, contain manganese minerals as a part of their gangue material, and the value of the manganese in fluxing is rated at the same price as iron. As manganese ore, under most circumstances, is a much more valuable material than iron ore, it is consumed as a flux only when it is of such low grade or so far from market that it cannot be used for other purposes, or when it is in such intimate association with the silver ore that it cannot be consumed otherwise without sacrificing the more valuable metal. In other words, manganese in association with silver ores, is a valuable ingredient in smelting, but, except under special circumstances, it does not pay to mine a good manganese ore for silver smelting purposes. Under peculiar conditions, such as the proximity of a smelter to manganese ore and the scarcity of a suitable iron ore, the manganese has been used. The use of manganese as a flux, therefore, may be considered rather an accidental application than an imperative source of consumption.

Manganese in the form of the mineral rhodonite, which is often of a beautiful pink color, is cut for jewelry and other ornamental purposes. Manganese in the form of its various salts is also employed for other lesser chemical, manufacturing, and medical purposes, as further mentioned in the next chapter.

In alloys, manganese is used in its metallic state, combined with other metals. Its value in this form depends on its contents of metallic manganese, and, in some of the alloys, on its comparative freedom from phosphorus, silica, and other injurious ingredients.

In the various uses of manganese for oxidizing processes, the manganese itself serves simply as a carrier for oxygen. For such purposes it is generally used in the form of the raw ore known as pyrolusite (peroxide of manganese); though, in some cases, especially in disinfectants, it is used in manufactured forms, as manganates and permanganates. In all cases, however, whether the manganese is in the form of its ore or of an artificial compound, its use for oxidizing purposes depends on the readiness with which it combines with oxygen in nature, or in the laboratory, and the ease with which, by simple means, it can be made to give up a part of it for manufacturing purposes. The oxygen thus obtained is known as the "available oxygen," as distinguished from the oxygen that cannot be taken from the ore or other compound in the ordinary processes of manufacture. As the amount of available oxygen in an ore depends on the amount of peroxide of manganese present, the market value of the ore is expressed in terms of peroxide. For use in glass-making, freedom from iron is a necessary condition of the manganese ore employed.

In the different applications of manganese for coloring materials, the manganese is used, not in the metallic form as in alloys, but as various compounds of the metal.*

THE ACTION OF MANGANESE IN ALLOYS WITH OTHER METALS.

Nature of metallic manganese.—Perfectly pure metallic manganese is exceedingly difficult to obtain, as it is usually mixed with more or less carbon taken up from the fuel used in its reduction, and even when it is pure it is such an unstable material that it has not yet been put to any practical use. When pure, it is of a gray color, or of a grayish-red like bismuth, and is not unlike cast-iron in general appearance. It is exceedingly hard, that prepared by Brunner cutting glass and hardened steel. It

* The various uses of manganese will be described in this and the following chapters, in the order of the above table.

has a specific gravity variously estimated at from 7.13 to about 8, which is close to that of iron (7.84). It melts at a white heat. Though very hard when first made, this metal rapidly crumbles to powder on exposure and passes into the oxide form. In fact so great is this tendency, that it has to be kept in some protecting oil or a closely sealed vessel to maintain it in its solid state. It decomposes water when brought in contact with it, taking up the oxygen and setting free the hydrogen. The pure metal was first isolated by Gahn in 1776, and was known in Germany as Braunstein-könig, or Braunstein metal. It was later prepared in various ways by John,* Deville,† Brunner,‡ and other chemists. It is only in an alloyed state, however, that it has proved of service in the arts.

Manganese mixes with iron and other metals readily in all proportions, and it has been found that a very small amount of iron will add stability to the product, counteracting the tendency of the manganese to oxidize and crumble. Manganese and iron alloys containing even over 80 per cent of the former ingredient are comparatively stable, but when the manganese is increased much over 90 per cent the product is liable to crumble. In many of the manganese alloys, not only those with iron, but also with other metals, the most noticeable effect of the manganese is the hardness that it gives to the resulting product, while other properties, such as ductility, elasticity, tensile strength, etc., depend more or less on the amount of manganese present and on the accompanying impurities. The hardness, however, is constant, and its influence on iron is well shown in Hadfield's manganese steel, which is harder than any known form of steel and is scarcely affected by the ordinary machining tools. (See pages 25–27.) The white color given by manganese is a feature of many of the alloys of that metal and is described later in this chapter in the case of manganese-bronze and Cowles' silver-bronze.

SPIEGELEISEN AND FERRO-MANGANESE.

Spiegeleisen and ferro-manganese are alloys of iron and manganese in different proportions. An alloy with less than

* Gehlen's Jour. Chem. Phys., III., p. 452.
† Ann. Chim. Phys., (3), XLVI., p. 182.
‡ Pogg. Ann., CL., p. 264.

twenty per cent of manganese is called spiegeleisen, and with from twenty per cent upwards it is called ferro-manganese. All degrees of admixture are made, from a spiegeleisen containing only 1 or 2 per cent of manganese up to a high grade ferro-manganese containing from 85 to 90 per cent or even more. Both are white or light gray in color and have a bright metallic lustre. Spiegeleisen has a brilliantly glittering crystalline structure, and hence its name, meaning "mirror-iron."

A spiegeleisen containing about 4 per cent of manganese often has a fibrous or columnar structure, and is known in Germany as *weissstrahl* and in France as *fonte-rubanée.** When the alloy contains 25 per cent or more of manganese, it assumes a compact, granular structure; with upwards of 50 per cent it often has an acicular crystalline structure.

All the alloys of manganese and iron contain considerable quantities of carbon, and analyses of certain grades of spiegeleisen sometimes show from 6 to 7 per cent. They are low in silicon, often containing less than 0.06 per cent of that ingredient. In other impurities they vary according to the nature of the ores used in their manufacture.

Spiegeleisen is more easily and more cheaply made than ferro-manganese, but its use is sometimes accompanied by difficulties which are overcome by the latter: it is often found that when enough spiegeleisen is added to the steel to supply the requisite amount of manganese, an injurious excess of carbon is imparted because of the amount of that ingredient in the spiegeleisen. Hence it becomes necessary to have a material richer than spiegeleisen in manganese, so that enough of the latter can be obtained in the steel without having to add too much carbon. This need is supplied by ferro-manganese, a material in which the manganese may be almost indefinitely increased. The increase, however, reaches a limit beyond which it is not advisable to go, since, as already stated, when the alloy contains over 90 per cent of metallic manganese it is apt to crumble.

The presence of manganese in iron has a marked effect in

* Phillips and Bauerman, Elements of Metallurgy, 1887, p. 255.

giving non-magnetic qualities to the alloy. According to R. A. Hadfield* this was observed as early as 1773 by Rinman, and later David Mushet† observed the same fact in his experiments with iron and manganese admixtures. The non-magnetic quality increases with an increase of manganese, and Mr. Hadfield, in his experiments with manganese-steel, has found that an approximate idea of the amount of manganese present can be obtained by testing the specimen with a magnet.

Methods of manufacturing spiegeleisen and ferro-manganese.—Spiegeleisen was formerly made by using a manganiferous iron ore in a blast-furnace, or by inserting small quantities of manganese ore in the iron ore charge. When the amount of manganese became large, however, great difficulties were experienced on account of the high temperatures required to smelt the metal and the loss due to the combination of the manganese with the slag. The more manganese contained in the charge the higher the temperature that is required, and a white heat is needed to reduce oxide of manganese alone. Consequently, in the early manufacture of ferro-manganese, the metal was reduced either in graphite crucibles as in Prieger's method in Germany, or in a Siemens' furnace as in the Henderson method in England, which was later improved by the Terre Noire Company of France. These processes were expensive, the loss was considerable, and the product limited. More modern appliances, however, and greater experience in the use of manganese ores have considerably facilitated the reduction of the metal, and now ferro-manganese is readily made in any properly arranged blast-furnace, with a high temperature and a strong hot blast. Coke is the best fuel, as it admits of a sharper blast and gives a stronger heat, but charcoal can be used, and Wm. P. Blake describes the manufacture of ferro-manganese with that fuel from a highly siliceous ore at Reschitza,‡ in Hungary. The other desirable features in the process besides those mentioned are: a highly basic slag, secured by large charges of lime; an abundance of fuel; and sufficient time. The basic character of the slag causes the

* Iron and Steel Institute, 1888, II., p. 55.

† David Mushet, Papers on Iron and Steel, 1840, p. 775.

‡ Trans. Amer. Inst. Mng. Eng., Vol. IV., 1875-6, p. 217.

saving of a considerable part of the manganese, which with a less basic, or an acid slag, would combine with the latter and be lost. If the slag is too basic, however, other difficulties are met; and even with all precautions, a loss of from 4 to sometimes over 15 per cent of manganese, the quantity varying according to the amount of the metal in the product to be obtained, is often sustained in smelting the ores.

HISTORY OF THE USE OF MANGANESE IN STEEL.

Introduced by Heath in 1839.—The introduction of manganese in improving the quality of iron and steel took place in England in 1839, as the result of the researches of Josiah Marshall Heath. Previous to this, the value of manganese for such purposes had been recognized by some metallurgists, and even as early as 1799 Wm. Reynolds* took out patents for its use. Between this date and 1837 three other patents were taken out in England for similar purposes, but all these failed to attract any attention. This was probably due, in some cases, to the imperfect methods proposed for its use, but it seems likely that the principal cause was that the inventors had not yet proved the advisability of employing manganese on a commercial scale. In 1830 Mushet† actually made, experimentally, a low ferro-manganese containing about 30 per cent of manganese, but his work at that time failed to make any change in the manufacture of steel. To Heath, therefore, is due the credit of having first introduced into general use the employment of manganese in the metallurgy of iron and steel, a use which has since grown to such importance that it is now well-nigh indispensable. The cause of the adoption of his methods was probably due to the fact that he conducted his experiments on a large scale and therefore, as soon as his invention was published, he had abundant evidence to prove its applicability on a commercial basis.

Cause, nature, and result of Heath's invention.—The immediate causes which led to Heath's discoveries were his

* J. S. Jeans, Steel: its History, Manufacture and Uses, London, 1880, p. 79.
† David Mushet, Papers on Iron and Steel, London, 1840.

endeavors to use, in the manufacture of steel, the low grade Wootz iron ore of Porto Nuevo, in the Madras district. He not only succeeded in this, but also completely revolutionized the steel industry of England. His original object was to improve both malleable iron and cast steel. In the first case he mixed with the cast or plate-iron, while fused in the puddling furnace, from 1 to 5 per cent of pure oxide of manganese, the sesquioxide being preferred. In the second case he mixed in the crucible, with the materials to be converted to steel, from 1 to 3 per cent of what he called carburet of manganese. The latter consisted of a manganese pig corresponding to white iron pig, and was composed of metallic manganese with a small percentage of carbon. It was made by smelting an intimate mixture of oxide of manganese and coal-tar. Previously the carburet of manganese had been simply a chemical curiosity, produced only in small quantities and with considerable difficulty; but by Heath's process it was obtainable in large amounts. By the addition of this material, it was found that the low grade steel made from the Wootz ore could be converted into an excellent product, easily malleable and weldable.

In 1839 Heath took out patents for his process, and made preparations for the introduction of his carburet of manganese among the steel makers of Sheffield. Further investigations proved to him that the same result as that brought about by the use of the carburet, could be obtained by simply inserting into the crucible the unsmelted mixture of oxide of manganese and tar, and that he could thus save the additional expense of converting the manganese into a carburet. He therefore moulded the manganese and tar into bricks, dried them by heating in a closed vessel, and used them in their raw state. In this form he soon found an extensive demand for his manganese compound among the steel manufacturers, who, after the first trial, realized the great advantage derived from it. Heretofore the best quality of steel in England had been made of high grade and expensive bar-iron from Sweden and Russia, but by the em-

ployment of Heath's process it was possible to make an equally good product from a comparatively low grade iron of English manufacture.*

Unfortunately for Heath, however, he had not taken out patents to cover the use of his mixture in the raw state, and this fact was taken advantage of by his agent and others to defraud him of the royalty on his invention. Years of litigation followed, and the case was tried many times over, passing through a series of vicissitudes of favorable and unfavorable decisions. Heath died during the proceedings in 1853 and the litigation was continued by his widow until 1855, when it was finally decided against her, thus ending one of the most celebrated suits in the history of English patents.

Though Heath was thus deprived of the well deserved fruits of his labors, his discoveries mark an epoch in the history of steel. Jeans, referring to the results of his invention, says,† "David Mushet has calculated that Heath's invention, causing, as it did, an immediate reduction of 30*l* to 40*l* in the price of good steel, resulted in an aggregate saving up to 1855 of not less than 2,000,000*l* sterling, while it also rendered England comparatively independent of the Swedish and Russian iron previously imported in such large quantities."

According to Percy, the secret of the success of Heath's mixture was the intimate association of the carbonaceous material, in the form of tar, with the manganese ore. The tar thoroughly impregnated the ore and when the compound was smelted, either alone or with the steel, the metal was easily reduced; whereas, with a less intimate mixture, a rapid corrosion of the smelting pots would have ensued, and it would have been much more difficult to obtain the manganese in the metallic state. To this fact Percy also ascribes the failure of previous attempts to introduce manganese into the manufacture of steel. The experience of

* John Percy, Metallurgy: Iron and Steel, London, 1864.

† Steel: its History, Manufacture and Uses, 1880, p. 30.

half a century, however, since Heath's first experiments has thrown more light on the subject of handling manganese ores, and what was then a new and difficult problem has since become a much less complicated one.

Increased use of manganese with the introduction of the Bessemer process.—The Bessemer process for making steel was first publicly announced by Henry Bessemer in 1856, but was not perfected until 1858. The principles of the patent were at that time ridiculed by the steel makers of England, and Bessemer, despairing of inducing them to adopt his methods, erected steel works in Sheffield for the employment of the new process. He subsequently realized large profits, and reduced the price of steel far below the quotations of other manufacturers,* thus compelling them to take out licenses to use the same process. The manufacture of steel was immensely increased by the introduction of this new method, and the demand for manganese became correspondingly large.

Robert Mushet's patent.—In 1856, shortly after the Bessemer process had been made known, Robert Mushet† took out patents in England for the improvement of steel by the introduction of a "triple compound" of iron, manganese, and carbon. This process was perfected in subsequent patents by the same inventor. It was claimed by others, however, that the patents were illegal, as similar compounds were already in general use throughout the kingdom, and, though the case did not come to trial, the exclusive rights of the patentee were not maintained.

Mushet's patent, however, was of the greatest importance to the successful working of the Bessemer process, as it overcame one of the main difficulties met in the early use of that method of steel making: it was found soon after the Bessemer process had been started, that a too extensive oxidation took place in the converter and that the whole of the carbon was burned off, the metal being completely reduced to wrought iron instead of steel. To remedy this, a certain amount of Mushet's compound, which represented the elements of spiegeleisen, was added in a molten

* Jeans, Steel: its History, Manufacture and Uses, 1880, p. 67.
† Ibid., p. 80.

state to the converter after all the carbon had been burned off from the metal within it. In this way the amount of carbon required for steel was restored by that in the spiegeleisen; or in other words, the metal was recarburized.

The spiegeleisen played other valuable parts in Bessemer steel, in reducing small quantities of oxide of iron formed during the process, in counteracting to a certain degree the bad effects of sulphur and phosphorus, and in other ways, as will be more fully explained later in this chapter. These effects, however, were directly dependent on the manganese in the spiegeleisen, and, though they were recognized, the exact part which the manganese played was not thoroughly understood; in fact, even yet the details of the various actions of manganese in steel are, in many respects, much disputed questions.

From Mushet's time dates the really extensive use of spiegeleisen, and later experiments have been largely in the line of making that material more cheaply and of better quality, and in bringing it up in its contents of manganese to a high grade ferro-manganese.

Manufacture of ferro-manganese by W. Henderson.—After Bessemer had proved the practicability of his steel process on a commercial scale, he soon saw the necessity of having a material high in manganese to supply that metal to the steel. The common spiegeleisen at that time contained only from 5 to 10 per cent of manganese, and sometimes as much as 6 or 7 per cent or more of carbon. It was made mostly in Germany, and the steel works in other countries obtained their supply from there. In using this material as a source of manganese it was found that, in order to get enough of the metal into the steel, such a large quantity of spiegeleisen had to be added that more than the desired amount of carbon was introduced. In making certain kinds of steel this had to be avoided, and therefore it became desirable to have something richer than spiegeleisen in manganese, so that enough of this metal could be added without adding an excess of carbon; in other words, a ferro-manganese was needed. Accordingly, at the instigation of

Bessemer, experiments to this effect were undertaken by W. Henderson, of the St. Rollox Chemical Works, Glasgow, who at first used the waste manganese from his chemical manufactures as a source of the desired material. Here, again, we have an instance of the remarkable foresight and ability of Bessemer in all matters pertaining to the manufacture of steel.

After a series of experiments, in which the great heat necessary and the corrosive action of the manganese were among the main difficulties, success was attained, and in 1865 the Henderson process was producing a ferro-manganese containing 25 to 30 per cent of metallic manganese. About the same time, according to Jeans, it was announced that a ferro-manganese, containing 75 per cent of metallic manganese, was being made by the M. Oscar Prieger process in Cologne.

Manufacture of ferro-manganese at Terre Noire, France — After Henderson had proved the possibilities of his method, it was adopted by the Terre Noire Company, of France. This company perfected the process and raised the percentage of manganese to 75 per cent, besides reducing the price 50 per cent.

MANUFACTURE OF SPIEGELEISEN AND FERRO-MANGANESE IN THE UNITED STATES.

New Jersey Zinc Company, 1870.—The manufacture of spiegeleisen in the United States was first commenced by the New Jersey Zinc Company, at Newark, N. J., in 1870. They used as a source of manganese, the residuum of the zinc ores after the extraction of the zinc. This residuum, known as "clinkers," contained iron and manganese; and spiegeleisen was made containing over 11 per cent of manganese and over 83 per cent of iron. Spiegeleisen often containing more than this amount of manganese is still made from the same material. (See chapter V.)

Willard P. Ward, 1874.—The first ferro-manganese, however, that was manufactured in the United States was made by Willard P. Ward, in 1874, at the Diamond Furnace, on Stump Creek, near Cartersville, Georgia. It was made of Georgia ores and contained over 55 per cent of metallic manganese.* Later,

* Ferro-manganese: Its Uses and the Facilities for its Manufacture in the United States, Willard P. Ward, 1876, p. 7.

the proportion of manganese was raised to over 67 per cent.* Mr. Ward's work is said to have represented the first successful manufacture of ferro-manganese in a blast-furnace.

Cambria Iron Company; Bethlehem Iron Company; 1875.—In 1875 the manufacture of spiegeleisen was started by the Cambria Iron Company, in Johnstown, Pennsylvania; and by the Bethlehem Iron Company, in Bethlehem, Pennsylvania. Spanish ores were used at both places.

Woodstock Iron Company; 1875.—In the same year of 1875 the manganiferous iron ores of Alabama were used in the manufacture of spiegeleisen at the Woodstock Iron Company's works at Anniston, in that state. According to W. P. Blake,† the spiegeleisen contained from 8 to 20 per cent of manganese and from 73 to 85 per cent of iron. It was made from a mixture of manganiferous iron ores containing over 20 per cent of manganese and ores containing something over 8 per cent.

Carnegie Brothers and Company.—Somewhat later, the manufacture of spiegeleisen was begun at the works of Carnegie Brothers and Company, Bessemer, Pennsylvania; and in 1883 the manufacture of ferro-manganese was introduced at the same place. The ferro-manganese now made there supplies not only their own consumption, but also that of certain other steel works. The variety for which there is most demand and which is made in largest quantities by Carnegie Brothers and Company, contains from 79 to 81 or 82 per cent of manganese. Some is made for special purposes containing 83 per cent and more of manganese, and, at times, a ferro-manganese containing over 90 per cent of manganese has been produced.

Colorado Coal and Iron Company.—In 1883 spiegeleisen was successfully made in Pueblo, Colorado, and at the present time it is produced at the works of the Colorado Coal and Iron Company at that place. The raw material is largely a manganiferous iron ore gangue from the silver veins of Leadville and elsewhere in the state, analyzing 9 to sometimes 51 per cent of manganese and 6 to 48 per cent of iron. The spiegeleisen

* Willard P. Ward, Trans. Amer. Inst. Mng. Eng., 1876-7, Vol. V., p. 612.

† Trans. Amer. Inst. Mng. Eng., IV., 1875-6, p. 219.

analyzes from 20 to 25 per cent of manganese, 4.8 to 5 per cent of carbon, 0.91 to 1.0 per cent of silica, 0.095 to 0.11 of phosphorus, and 0.14 to 0.16 per cent of sulphur. Ferro-manganese is also now made containing forty per cent of manganese.*

THE USE AND EFFECT OF MANGANESE IN STEEL.

General statement.—The application of manganese in steel, as already shown, has been a common practice ever since the publication of Heath's patents for its use in 1839, but the exact part that it plays in the metallurgy of steel has long been a matter of discussion, and, in many respects, is still a very much disputed question.

The use of spiegeleisen as a recarburizer in steel, to replace the carbon that has been burned off during its manufacture, depends on the existence of carbon in the spiegeleisen and has been mentioned on page 16. The manganese itself in the spiegeleisen, however, also plays very important parts. The fact is well known that its most valuable effect is in reducing the small quantities of oxide of iron formed in the steel during the final melting. The manganese thus used leaves the steel and goes into the slag; but it has been found that by allowing a certain quantity of it to remain, other valuable results are obtained in counteracting phosphorus, removing and counteracting sulphur, and in other ways. Even in late years, however, the quantity that should be left in steel has been greatly disputed, and not twenty years ago many prominent authorities thought that more than 0.75 per cent greatly injured the tensile strength, ductility and other properties of steel, while still others denied the advisibility of even this amount. Now, steel rails, though they still often contain less than 0.5 per cent of manganese, are frequently made with over 1.5 per cent and, in some cases, over 2 per cent. Recently, the experiments by R. A. Hadfield, on manganese steel, show that a metal containing manganese from the proportions commonly used up to over 21 per cent,

* The survey is indebted to the kindness of Mr. I. Grove, Superintendent of the Colorado Coal and Iron Company for the analyses of the ores used and of the spiegeleisen and ferro-manganese produced at his works. The former are given under the heading of Rocky Mountain manganese ores and the latter in the list of analyses of spiegeleisen.

possesses remarkable properties; and that the mixture containing 14 per cent of manganese and not over 1 per cent of carbon, especially, shows a wonderful combination of hardness and toughness. Though these high-manganese steels are not at present used on account of mechanical reasons, yet the value of steel with from 0.5 to over 1.5 per cent for certain purposes is now very generally recognized. The present state of our knowledge concerning the effects of manganese have been carefully summarized by Professor Henry M. Howe, in his late work, the Metallurgy of Steel.

Effect of manganese on oxide of iron.—As just stated, the most important action of manganese is the reduction of the oxide of iron in the steel. During the final melting in the Bessemer process, the steel absorbs from the blast a certain amount of oxygen, from 1 to 2 per cent and sometimes more, which combines to form oxide of iron. The presence of this compound renders the steel difficult to forge, or, as it is commonly expressed, "red-short." This defect is counteracted by the addition of small quantities of manganese in the molten steel. The manganese has a greater affinity for oxygen than iron has, and the action which goes on is the absorption by the manganese of the oxygen in the oxide of iron, forming oxide of manganese. The latter combines with the slag to form a proto-silicate and is thus separated from the steel. The oxide of iron in the steel is supposed by some to be in the ferroso-ferric form (Fe_3O_4), which is the form of iron in magnetic ore. Others believe it to be in the ferrous form (FeO). Howe inclines to the latter supposition and suggests that some of each may be formed, or, that a more general distribution of the oxygen throughout the iron may take place; and that "part or all the oxygen may, like hydrogen and carbon, be united with the whole of the metal." *

If the manganese applied played no other part than to combine with the oxides of iron, the question as to which formula is correct would be more easy of solution, but, as pointed out by Howe, some of it seems to combine directly with the slag, with-

* Metallurgy of Steel. New York, 1890.

out the intervention of oxide of iron, and possibly a part of it is volatilized. Also, various combinations of manganese with the impurities in the steel are supposed to go on, and these, as well, may influence the size of the charge of manganese necessary to have the desired effect on the oxide of iron. The determination of this question is a most important one, as it is directly connected with the amount of manganese necessary.

Besides the oxygen thus combined with the steel there is also a certain amount of it in the small particles of slag mechanically enclosed in the metal. The oxygen itself in this form is less injurious than in its other form, but the removal of the slag particles is a very desirable object and is largely effected by the manganese. In this case Howe thinks that the manganese combines with the silicate of iron composing the particles of slag and forms a double silicate of iron and manganese, which coalesces much more readily from its finely disseminated condition and, rising to the surface of the metal, mixes with the main body of the slag above. "This," says Howe, "does not mean a greater fusibility, but the manganese makes a silicate which is either lighter or, more probably, which coalesces easier."

Effect of manganese on sulphur.—Manganese counteracts, to a greater or less degree, the quality of hot-shortness produced by the presence of sulphur, phosphorus, copper and other impurities. Howe* shows that manganese acts on sulphur both by removing it bodily from the cast iron, and probably also from the steel, as well as partly neutralizing the effects of what remains. Percy,† as early as 1864, quotes Mr. Perry of the Ebbw Vale Iron Works, as stating that whenever there is much manganese in the slag there is also a considerable proportion of sulphur associated with it, pointing, as has been since proved, to the removal of the latter from the molten metal. Percy also thinks that this association of manganese and sulphur may help to explain the origin of the mineral helvite, which consists of manganese, iron, glucinum and sulphur.

Effect of manganese on phosphorus and on carbon.—Accord-

* Metallurgy of Steel. New York, 1890.

† Metallurgy: Iron and Steel. London, 1864

ing to Howe, though manganese counteracts the hot-shortness caused by phosphorus, it does not counteract the cold-shortness produced by that impurity. He thinks the first result is accomplished by rendering the metal more fluid and plastic when molten, and thus counteracting the tendency toward crystallization in the steel caused by phosphorus, rather than by forming a phosphide of iron, or other chemical compounds.

Manganese is said to increase the power of carbon to combine with iron at very high temperatures and to restrain its separation as graphite at lower ones, thus acting in an opposite direction to silicon, which tends to cause carbon to separate.

Effect of manganese on the physical properties of steel.—According to A. L. Holly* manganese in proportions of 0.75 to 1 per cent in steel gives hardness, toughness, malleability and elasticity; and that its hardening influence† up to 0.20 to 0 30 per cent is slight.

The influence of manganese on the ductility of steel has been a much disputed point, and is often supposed to decrease it; but Howe‡ shows that the effect depends on the amount of manganese present and that, "While 1.5 to 2.5 per cent of manganese is nearly universally admitted to cause brittleness, steel with 8 per cent of manganese is astonishingly ductile; with further increase of the manganese the ductility again diminishes. Steel with 8 to 10 per cent of manganese, though exceedingly tough, is so hard as to be employed without quenching for cutting tools."

Though manganese is apt to raise the melting point of steel, it often adds fluidity when the metal is molten, and this fact sometimes plays a beneficial part in the manufacture of steel castings. P. G. Salom‖ states that low-carbon steel, to which is added about 0.3 per cent silicon, is very pasty and it is only in the largest castings that it can be poured without chilling. Manganese corrects this trouble to a great extent, though some-

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*Tests of Steel, Trans. Amer. Inst. Mng. Eng., II., 1873-4, p. 117.

†Trans. Amer. Inst. Mng. Eng., VI., 1887-8, p. 110.

‡Metallurgy of Steel. New York, 1890, p. 42.

‖The Manufacture of Steel Castings, Trans. Amer. Inst. Mng. Eng., XIV., 1885-6, p. 128.

what at the expense of softness and ductility. The castings are less liable to crack in the moulds, however, since the metal is much less red-short.

The influence of manganese on slag is very marked, giving it a green color and considerable fluidity. Percy* has observed a pink color in certain slags which he also ascribes to manganese. Manganese also gives the slag such a strong corrosive power that its influence on the linings of furnaces is often very considerable.

Amount of manganese added to steel.—It has been shown that manganese is a most important agent in the modern manufacture of steel, not only removing from it bodily certain impurities, but also counteracting many of those that remain. The manganese used to remove the oxygen, which is its most important object, leaves the iron and goes into the slag after it has accomplished its purpose. Therefore, if only just enough manganese were added to reach this end, the steel, as finally cast, would contain none of that metal; consequently it is found advisable to add more than enough to reduce the iron oxide and to have a certain amount, varying according to the kind of steel wanted, in the final product. This is especially necessary where there is any considerable amount of sulphur or phosphorus present, in order to counteract the deleterious effects of those impurities. The amount that is necessary, however, is very uncertain. Manganese is added in the form of spiegeleisen or ferro-manganese and from one to five per cent of these materials is used. The quantity varies according to their metallic contents, and according to the amount of manganese it is desired to leave in the steel after that which has combined with the oxygen has gone into the slag.

Dudley's formula.—Dr. Charles B. Dudley in his article on the Wearing Capacity of Steel Rails in Relation to their Chemical Composition and Physical Properties, † gives the following two formulas for percentages of carbon, phosphorus, silica and manganese in good steel rails. The first he considers the best, but admits the second as necessary since the first is lower in phosphorus than manufacturers of rails in this country can work.

* Metallurgy: Iron and Steel, p. 506.

† Trans. Amer. Inst. Min. Eng., IX., 1880-81, p. 356.

FIRST.

Carbon	0.334
Phosphorus	0.077
Silicon	0.060
Manganese	0.491

SECOND.

Carbon, between 0.25 per cent and 0.35 per cent with aim at	0.30
Phosphorus, not above	0.10
Silicon, not above	0.04
Manganese, between 0.30 and 0.40 with aim at	0.35

Dudley's paper created a great deal of discussion and brought out the results that had been obtained by many others in similar investigations.

Wendel's formula.—Dr. August Wendel * in the same year presented the following formula for good rolling steel:

$$Mn = 0.8\ (C + \tfrac{1}{2}\ Si) + 4\ P.$$

the figures stand for percentages and the letters for manganese, carbon, silica, and phosphorus respectively. Howe quotes this formula in his Metallurgy of Steel, and while acknowledging its applicability in Wendel's practice, says that it cannot be used in all cases.

Hence, it will be seen that while it is now universally acknowledged that manganese gives certain valuable properties to steel, yet the quantities to be used under different conditions are still greatly in dispute. If it were a question simply of the effect of manganese on the steel itself, it might be much more easily solved, but it also involves the action of manganese on carbon, silicon, phosphorus, sulphur, and probably other ingredients, as well as the action of these ingredients when thus effected, on the steel and on each other. Thus there is a labyrinth of complications which will require the highest art of the metallurgists to solve.

* Trans. Amer. Inst. Mng. Eng., IX., 1880-81, p. 564.

HADFIELD'S MANGANESE STEEL.

Properties of Hadfield's manganese steel.—It has already been shown that the use of small quantities of manganese in steel has become a universal practice, but the amount of it is very small compared with the mass of the steel and usually ranges from less than 0.5 to 2 per cent. Lately, however, R. A. Hadfield, of the Hadfield Steel Foundry Company, Sheffield, England,* has made and described a steel with a larger proportion of manganese, sometimes containing over 20 per cent of that metal. The most remarkable feature of this steel is its excessive hardness, which is so great that the ordinary machining tools have little effect on it. If, however, suitable tools can be made for handling it, this quality, which is now one of the great drawbacks to its use, will doubtless make it a most valuable material for many purposes.

The strength and toughness of the steel vary considerably according to the amount of manganese used, and also according to the per cent of carbon present. The different mixtures are described by Hadfield as follows: "That containing from 2½ to 6 per cent is extremely brittle in its cast state; then a return in strength gradually takes place, and, with about 9 to 10 per cent, a cast bar, 2½ inches square, can be bent considerably out of the straight without breaking. This continues up to about 14 or 15 per cent when a decrease occurs in actual toughness, though not in transverse strength, and after about 20 per cent is passed, a rapid decrease again takes place. It should be stated that these remarks apply especially to the material in its cast state. * * * The peculiar gain in strength noticed by an increasing addition of manganese is still more closely shown with the material in its forged state, * * * the maximum strength being obtained with the 14 per cent material. Possibly, if ferro-manganese was made with less carbon, or if pure metallic manganese could be obtained, the maximum of strengh might occur with even higher manganese; but now, as the higher percentages are approached—say over 16 per cent—the experiments become more complicated owing

* Jour. of Iron and Steel Inst., 1888., II.

to the presence of 1½ to 2 per cent of carbon, which must necessarly interfere with the action of the manganese." *

In addition to these qualities, the metal is not so liable to honeycomb as ordinary steel and the addition of silica is unnecessary; it cools more rapidly; it is very fluid; it has a strong electrical resistance and low magnetic characteristics.

Uses of Hadfield's manganese steel.—This material has not yet been put to any considerable commercial use on account of the difficulty of handling it, but its valuable properties, and especially, as Howe suggests, its "marvelous combination of ductility with certain kinds of hardness," should make it valuable; and it seems probable that means will be found to treat a material which can be devoted to so many useful purposes. Tests of it for car wheels have been made and have proved highly satisfactory. It has also been proposed for certain kinds of tools and various other uses in which a combination of hardness and toughness is necessary. Hadfield, † in speaking of its adaptability for car wheels, says: "On the Nottingham Tramways a set ran over 30,000 miles under severe conditions, the gradients averaging as much as 1 in 18 for about one half the route of the daily journey. In this case a peculiar point was noticed, viz., that, whereas the cast-iron wheels are liable to slip when going down an incline, the chilled break-blocks bite much more effectively on manganese wheels, enabling the car to be stopped sooner. The Chester Tramways Co. have had a set running for over two years, which up till now have run over 45,000 miles, and are not yet worn out. Wheels of this description can be tested with more than one hundred blows with a heavy sledge hammer without fracture occurring, and at the same time the type is so hard that a chisel will not touch it. A set put to work in America has already run 200,000 miles, under heavy engines of the consolidation type, on the New York and New England Railroad. The life of the ordinary chilled iron wheel does not average more than 50,000 miles."

This steel has also been proposed for resistance coils in

* Loc.. cit., p. 42.

† Jour. of the Iron and Steel Inst., II., 1888, pp. 51-52.

electric work on account of its high electric resistance, which has been found by Professor Barrett, of Dublin, to be about eight times that of ordinary steel and iron, and thirty times that of copper. Its use as the base of dynamo machines has also been suggested on account of its highly non-magnetic properties.

Materials for making Hadfield's manganese steel.—Manganese steel is made best, according to Mr. Hadfield, from decarbonized iron or mild steel, to which ferro-manganese in a molten state is added. It is necessary to keep the carbon low, and in the steel containing 14 per cent of manganese, the carbon should not amount to over 1 per cent. This has proved one of the main difficulties in making high manganese steel, as even the best ferro-manganese contains considerable carbon. To avoid it as much as possible, however, a ferro-manganese rich in metallic manganese, at least 80 to 84 per cent, should be used, thereby getting in the largest possible amount of manganese to the least carbon. About 0.50 per cent of manganese is lost in the process, and this must be allowed for in making the charge for the alloy. The mixture of the iron and manganese can be best made in a ladle, as the latter metal is apt to attack a crucible.

PRODUCTION OF SPIEGELEISEN AND FERRO-MANGANESE IN THE UNITED STATES.

As already stated, the New Jersey Zinc and Iron Company were the first to produce spiegeleisen in the United States. They began in 1870 and their output in 1872, 1873, and 1874 was:*

Production of spiegeleisen in the United States, 1872–1874.

1872	4,072 tons.
1873	3,930 "
1874	4,070 "

The manufacture was taken up by other companies in 1874 and 1875, and the production of the United States since 1875 as given by Mr. James M. Swank, Secretary of the American Iron and Steel Association, in his Statistical Report of May 1st, 1890, has been as follows:

*J. S. Jeans, Steel: Its History, Manufacture and Uses.

Production of spiegeleisen and ferro-manganese in the United States, 1875–1889.

YEARS.	NET TONS.	YEARS.	NET TONS.
1875	7,832	1883	24,574
1876	6,616	1884	33,893
1877	8,845	1885	34,671
1878	10,674	1886	47,982
1879	13,931	1887	47,598
1880	19,603	1888	54,769
1881	21,086	1889	85,823
1882	21,963		
		Total	439,860

It will be seen that the production has steadily increased since 1872, the years 1873 and 1887 alone having fallen a few tons each behind the year before, and that the production of 1889 shows an increase over 1888 greater than the increase in any one year previous. The supply of domestic ores is not sufficient for the demand in the manufacture of spiegeleisen and ferro-manganese, and considerable quantities of foreign ores are used. (See chapter IV.).

The production for the census year of June 30, 1889, to June 30, 1890, was 149,959 tons. This is almost one and three-quarter times the production of the calendar year of 1889, and shows a much greater increase than any previous year since the manufacture of spiegeleisen and ferro-manganese was begun in the United States.

IMPORTS OF SPIEGELEISEN AND FERRO-MANGANESE INTO THE UNITED STATES.

The Survey is indebted to the kindness of Mr. James M. Swank, Secretary of the American Iron and Steel Association, for the records of the imports for the following years:

Imports of spiegeleisen and ferro-manganese into the United States, 1887–1889.

	Gross tons.
1887	157,279
1888	71,605
1889	99,481

It will be seen that the imports are much larger up to 1889 than the domestic manufactures, though the relative difference

has become very much less than in former years, and possibly the production of the census year may reverse the standing. The excess of importation over domestic production in late years has undoubtedly been largely due to the same cause as prompted the importation of foreign manganese ores, that is, the limited quantity of such ores produced in this country.

At the time the New Jersey Zinc Company first manufactured spiegeleisen twenty years ago, the consumption in the United States was entirely supplied from Europe and amounted to a maximum yearly importation of about twenty-five thousand tons. Prof. Wm. P. Blake,* speaking in 1876, states that the importations were mostly from Germany and amounted then to from twenty to thirty thousand tons yearly, while that of domestic manufacture amounted to seven thousand tons per annum.

ANALYSES OF SPIEGELEISEN AND FERRO-MANGANESE.

Analyses of spiegeleisen made by the New Jersey Zinc Company.†

	I.	II.
Manganese	11.586	11.67
Iron	83.250	83.23
Silicon	0.367	0.99
Phosphorus	0.196	0.19
Carbon	4.632	4.02
	100.031	100.10

* Amer. Inst. Mng. Eng., IV., 1875-6, p. 218.

† J. S. Jeans, Steel: Its History, Manufacture and Uses, 1880.

*Analyses of ferro-manganese manufactured by Willard P. Ward at the Diamond Furnace, Georgia.**

	I.	II.
Manganese	55.22	55.99
Silicon	0.081	1.671
Phosphorus	0.471	0.390
Carbon	1.86	.....
Slag	26.58	.....

No. I. was the first ferro-manganese made at the Diamond Furnace. Analyzed by Otto Wuth, of Pittsburg.

No. II. was a sample of ten tons shipped to the Vulcan Iron Works, of St. Louis. Analyzed by Chauvenet and Blair.

Analyses of spiegeleisen manufactured by the Woodstock Iron Company, Anniston, Alabama.†

	I.	II.	III.	IV.
Manganese	10.18	8.14	14.13	20.69
Iron	85.11	85.98	80.37	73.86
Silicon	0.95	0.88	0.38	0.93
Phosphorus	0.10	0.17	0.18	0.197
Carbon	3.66	4.83	4.94	4.32

Analysis of ferro-manganese imported into the United States in 1890.

Metallic manganese	80.29
Phosphorus	0.337

* Ferro-manganese: Its Uses and the Facilities for its Manufacture in the United States, by Willard P. Ward. St. Louis, 1876, p. 7.

† W. P. Blake, Trans. Amer. Inst. Mng. Eng., IV., 1877, p. 219.

*Analyses of spiegeleisen and ferro-manganese manufactured by the Colorado Coal and Iron Company of Pueblo, Colorado.**

	SPIEGELEISEN.			FERRO-MANGANESE.
Manganese	25.96	23.80	20.50	40.00
Silicon	.93	.91	1.00	.75
Phosphorus	.095	.100	.110	.100
Carbon	4.80	5.00	5.00	5.500
Sulphur	.150	.140	.160	.130

Analyses of the best spiegeleisen imported into New York in 1868, 1869 *and* 1873.†

	1868.		1869.		1873.	
Manganese	9.142	10.625	10.568	10.223	11.130	10.22
Iron	85.57	84.455	84.122	84.869		
Silicon	.068	.868	.268	.384		
Phosphorus	.037	.044	.104	.027	.039	.06
Sulphur		.002		.001		
Carbon	5.048	4.804	4.907	4.461		
Copper	.032	.034	.036	.031	.279	.20
Nickel and Cobalt	.005	.005	.004	.002		
Aluminum	.082	.045	.032	.012		
Calcium	.015	.016	.021			
Total	99.999	99.898	100.062	100.010		

* Furnished by Mr. I. Grove, Superintendent of the works.

† Mineral Resources of the United States, 1883-84, p. 561.

*Analyses of low-manganese pig-iron, of spiegeleisen and of ferro-manganese from St. Louis furnaces, Marseilles, France.**

	Lamellar pig.	SPIEGELEISEN.		Ferro-manganese.		Gray steely pig.
		A.	B.	A.	B.	
Manganese	4.640	10.930	19.500	39.900	84.960	3.310
Iron	90.070	†83.958	†75.562	†54.436	8.550	†89.029
Silicon	1.325	0.690	0.168	0.186	0.660	2.740
Phosphorus	traces.	0.002	0.015	0.020	0.005	0.015
Sulphur	0.048	0.010	0.005	0.008	0.035	0.006
Total Carbon	3.627	4.410	5.750	5.450	5.700	4.900
Total.	99.710	100.000	100.100	100.100	99.910	100.000

Analyses of French and German weissstahl, spiegeleisen and ferro-manganese.‡

	Manganese.	Iron.	Silicon.	Phosphorus.	Sulphur.	Carbon.		
						A.	B.	C.
Eisenerz Weissstahl	.....	.....	0.09	0.02	0.77	.....	.....	3.40
Wissen Spiegeleisen	11.10	.....	0.25	0.03	0.06	.....	4.10	.....
French Spiegeleisen	20.50	75.86	0.46	0.08	.....	.....	.....	5.25
French Ferro-manganese	51.80	41.70	0.46	0.13	.....	.....	.....	6.00
French Ferro-manganese	74.60	18.20	2.73	0.24	.....	.....	.....	5.40
French Ferro-manganese	87.90	6.78	1.49	0.29	.....	.....	.....	6.50
French Ferro-silicon	20.50	66.75	10.20	0.18	.....	.....	.....	2.65

* Quoted from M. Jordan, Managing Director, by Dr. R. W. Raymond, Trans. Amer. Inst. Mng. Eng. VI., 1877-8, p. 198.

† By difference.

‡Metallurgy, by J. A. Phillips and H. Bauerman, 1887, p. 257.

Of the three columns under carbon, the first, *a*, represents the amount of graphitic carbon, the second, *b*, that of combined carbon, the third, *c*, the total amount of that element present.

*Table showing the quantity of manganese in various kinds of foreign steel.**

Steels.	Per cent Manganese.	Steels.	Per cent Manganese.
Krupp's crucible cast steel Essen	0.437 to 0.438	Hœrder steel	0.107 to 0.170
		Cannon steel (Terre Noire)	0.240
Bochum cast steel	0.312 to 0.317	Rail steel (Creusot)	0.550
Haspor Steel	0.327 to 0.332	Rail steel (Petit Gaudin)	0.560
Manganese steel of Ludwig in Berlin	0.303	Rail steel (Terre Noire)	0.860
Fine piano wire	0.035	Rail steel (Seraing)	0·650

ALLOYS OF MANGANESE WITH METALS OTHER THAN IRON.

Early experiments.—The first reference to the use of manganese in an alloy was made in England by Dovey † in a patent taken out in 1773. His object was, as he explained, to make "a metal of the color of and in all respects resembling gold," by mixing "mangonize oar" with copper, tin and zinc. Though his ambitious desire to imitate gold was not accomplished, his patent is of interest as showing the early attempts to use manganese in alloys.

Berthier made, experimentally, many alloys containing manganese and described their properties early in this century. Dr. John Percy also investigated the effects of admixture of manganese and other metals, and the results of his investigations have greatly assisted the commercial manufacture of such alloys at the present day.‡

Characteristic features.—In spite of these early experiments, the art of using manganese in alloys with other metals than iron

*Quoted by Mineral Resources of the United States, 1883-4, from Kessler, in Dingler's Polytechnisches Journal.

† R. A. Hadfield, Proceed. Civil Engineers, XCIII., Pt. III., 1888.

‡ E. H. Cowles, Trans. Amer. Inst. Mng. Eng. XVIII., 1888-90, p. 495.

may be said to be yet in its infancy. The alloys known as manganese bronze, silver-bronze and other manganese-bearing alloys, however, have many valuable properties, and their manufacture, especially that of manganese-bronze, has already become an important industry.

Among the most marked effects that manganese has on these alloys are the hardness it imparts, the influence it exerts, when present in various proportions, on elasticity, ductility, tensile strength, fusibility, fluidity, etc.; the low magnetic properties and the high electric resistance that it gives the alloy, and the power that it exerts in imparting a white color to copper and other metals. The whitening power of manganese, as shown in the description given further on of Cowles' silver-bronze is, in some cases at least, greater even than that imparted by nickel.

Manganese-bronze.—The name manganese-bronze is applied to alloys of manganese and copper, and alloys of manganese, copper and iron. Certain forms of these alloys possess remarkable strength, toughness and hardness, and have been devoted to various uses. The largest use of manganese-bronze in this country, however, is as a material for the screw propellers of steamships. It is manufactured by B. H. Cramp and Company, of Philadelphia, and by the Cowles Electric Smelting and Aluminum Company, of Lockport, New York. Many of the new cruisers and gunboats of the United States Navy, as well as many other large steamers, are fitted or being fitted with manganese-bronze propellers.*

Manganese-bronze mixed with tin and lead has been used for machinery bearings and other similar purposes.

In 1870 M. A. Valenciennes† described several alloys of cobalt and copper, and of manganese and copper. He made metallic manganese first, by reducing pure peroxide with charcoal in a magnesia crucible. The metal thus obtained was brittle,

* Among these are the cruisers Philadelphia, Baltimore, Newark and Vesuvius; the gunboats Yorktown, Bennington and Concord. Several of the largest of the trans-Atlantic steamers also have manganese-bronze propellers, among them being the City of Paris, the City of New York, the Etruria, Umbria, Teutonic, Augusta Victoria and many others.

† Notes sur le cobalt, le manganese et leur alliages avec le cuivre. Comptes Rendus Acad. Sci., 1870, LXX., p. 607.

white and altered rapidly in the air, going into the form of a red oxide. With this metal he made an alloy containing 20 per cent of manganese, and from it made five others containing respectively 3 per cent, 5 per cent, 8 per cent, 12 per cent and 15 per cent of manganese. They all resembled the alloys of copper and tin, and like them were hard, sonorous, and easily melted.

The alloy containing 15 per cent of manganese was of a gray color, very hard and brittle. It melted like brass and was very fluid. It did not appear to undergo alteration even after considerable time.

The alloy containing 12 per cent of manganese was also very brittle and hard. When freshly turned it was of a gray color, but soon changed to a brass yellow.

The alloys containining 3, 5 and 8 per cent of manganese seemed to have lost the brittle quality given by a larger per cent of manganese. They were ductile, could be hammered, passed through rolls and converted into thin sheets.

Parson's manganese-bronze.—In 1876 Mr. Parson took out a patent in England for the manufacture of certain alloys of copper, or ordinary bronzes, with manganese. In 1878* this alloy was manufactured at the works of the White Brass Company and sold under the name of "Parson's Manganese Bronze."

The alloy, as then manufactured, was composed of any ordinary bronze combined with manganese. The latter appears to have the effect of cleansing the metal of all oxide and renders it of a very uniform and close grained consistency, a fresh fracture having a structure as fine and close as steel. The alloy possesses increased strength, toughness and hardness, the latter being especially marked. In color it is like good gun metal, but is of a rather brighter and more golden hue. "It can be forged at a red heat and rolled into rods and sheets, and drawn into wires and tubes. The best results are obtained in using spiegeleisen or ferro-manganese in varying proportions, according to the requirements of the bronze." Specimens were tested at the Royal Gun Factories and it was found that cast specimens had a tensile strength and elongation equal to medium

* Ure's Dict. of Arts, Manufactures and Mining, Vol. IV., Supp. 1878, pp. 160-161.

quality wrought iron, and a higher elastic limit. All the forged specimens had a considerably higher tensile strength and elongation.

In connection with the fact already mentioned, that manganese frees the copper from oxide, it is of interest to mention that Richard Pearce * has found as much as 3 per cent of sulphide of manganese in copper matte containing 50 to 60 per cent of metallic copper, made at Butte City, Montana, and he states that its presence seems to render the copper less liable to oxidize. In the case of manganese-bronze, the metallic manganese probably acts as a reducing agent for any oxide of copper that may be present, and in the case of the Butte City matte the sulphide possibly plays a somewhat similar part.

Cowles' silver-bronze.—Cowles' silver-bronze is an alloy of manganese, aluminum, zinc and copper, with a certain proportion of silicon. It is manufactured by the Cowles' Electric Smelting and Aluminum Company, of Lockport, New York, and is the result of a long series of experiments by the Cowles brothers. It is made as a substitute for German silver and has only lately been put on the market. The following description of the silver-bronze alloy, and the causes which led to its manufacture, are given by Mr. Eugene H. Cowles.† After speaking of the difficulties attending the use of manganese-bronze, he says:

"In order to overcome the two prime difficulties, that of casting and that of corrosion, we have introduced a small percentage of aluminum into the alloy, with the happiest effect.

"The successive steps that have been pursued are recorded in a list of upwards of two hundred distinct mixtures of the several metals, copper, zinc, tin, lead, aluminum, iron and manganese and the metalloid silicon, and experiments upon the same in ascertaining the tensile strength, ductility, color, etc. The most important determinations derived from this list of experiments appear to be about as follows:

"1. That pure metallic manganese exerts a bleaching effect

* Trans. Amer. Inst. Mng. Eng. XI., 1882-83, p. 59.

† Physical Properties of some of the Alloys of Manganese, Copper and Aluminum. Trans. Amer. Inst. Mng. Eng., XVIII., 1889-90, pp. 494-496.

upon copper, more radical in its action even than nickel. In other words, we found that 18½ per cent of manganese present in copper produces as white a color in the resulting alloy as 25 per cent of nickel would do, this being the amount of each required to remove the last trace of red.

"2. That upwards of 20 or 25 per cent of manganese may be added to copper without reducing its ductility, although doubling its tensile strength and changing its color.

"3. That manganese, copper and zinc, when melted together and poured into moulds, behave very much like the most 'yeasty' German silver, producing an ingot which is a mass of blow holes, and which swells up above the mould before cooling.

"4. That the alloy of manganese and copper by itself is very easily oxidized.

"5. That the addition of 1.25 per cent of aluminum to a manganese–copper alloy, converts it from one of the most refractory of metals in the casting process, into a metal of superior casting qualities, and the non–corrodibility of which must, in many instances, be far greater than that of either German or nickel silver.

"The 'silver–bronze alloy' especially designed for rods, sheets and wire has the following composition: Manganese, 18; aluminum, 1.20; silicon, 5; zinc, 13, and copper, 67.5 per cent. It has a tensile strength of about 57,000 pounds. on small bars, and 20 per cent elongation. It has been rolled into thin plate; and drawn into wire .008 inch in diameter. A test of the electrical conductivity of this wire (of size no. 32) shows its resistance to be 41.44 times that of pure copper. This is far lower conductivity than that of German silver, and is a matter of considerable importance to electricians who may wish a cheaper and better material than can be had at present, from which to construct resistance coils."

Manganese with aluminum and with magnesium.—Alloys have been made by Terreil composed of manganese with aluminum and manganese with magnesium.* The aluminum alloy

* Bull. Soc. Chim., XXI., p. 289. Quoted in Dict. of Chem., Henry Watts, 3d Supplement, Vol. II., 1881., p. 1264.

was very hard and scratched glass. The magnesium alloy was softer.

Alloys of manganese with copper, zinc, tin and lead.—In 1870 J. F. Allen* described several alloys of manganese with copper and with zinc. The first were made by reducing a mixture of oxide of manganese and oxide of copper in a plumbago crucible with charcoal. Later, a Siemens furnace was used. An alloy containing copper 75 per cent, manganese 25 per cent, was very hard and very brittle when hot, and when cold was still hard, but was highly elastic and was rolled with ease. With proportions of manganese from 5 to 30 per cent, the alloy was malleable, ductile and had a considerably greater tenacity than copper. When zinc was added to the manganese–copper alloy in certain proportions, products were obtained which Allen says "possess the advantage both over German silver and yellow metal, that whereas, the one will only roll cold and the other hot, the manganese alloys roll from hot to cold." In other respects the manganese–copper–zinc alloy very closely resembled some grades of German silver, though not the best. A manganese–copper alloy was made to combine with tin, lead and other metals, and from these, castings for machinery-bearings were made.

Five sample alloys were made:

1. Manganese–copper alloy, varying from 5 to 35 per cent manganese; made in form of ingot, sheet or wire.

2. Copper–zinc–manganese alloy in different proportions and different forms.

3. Copper–zinc–manganese–tin alloy in form of ingots and bearings.

4. Copper–manganese–tin in several different proportions as bars.

5. Copper–manganese–lead alloy.

Other alloys.—According to D. C. Davies,† "at the smelting works at Dillenburg, in Hesse–Nassau, several valuable alloys of the metal (manganese) are made with iron, copper and tin.

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* Chem. News, Vol. XXII., 1870, p. 194.

† Earthy and other Minerals and Mining. London, 1884, p. 283.

Mansfield refined copper, for example, mixed with 11 per cent of manganese forms the pure manganese-bronze, which is capable of bearing a heavy breaking strain. A mixture of copper 85, tin 6, zinc 3, and cupro–manganese 3 parts, gives a casting that will bend to a right angle before showing fine cracks. An alloy also of great hardness, but workable with tools, is also made at the same works with 80 parts of copper, 10 parts of tin, and 10 parts of manganese. Varying proportions of the metal are used with iron, tin, copper and zinc to produce results adapted to particular uses."

CHAPTER III.

MODERN USES OF MANGANESE—*Continued.*

OXIDIZERS AND COLORING MATERIALS.

Elements of value of manganese ore for oxidizing purposes.—The manufacture of chlorine consumes by far the larger part of those ores of manganese that are used for oxidizing purposes. As already stated, the value of an ore for such purposes depends upon the amount of oxygen that can be derived from it by means of heat or acids, or both. This product is known as the "available oxygen" of the ore, as distinguished from the oxygen that cannot be taken from the ore in the ordinary processes of manufacture. The only manganese ores in which available oxygen exists in commercially important quantities are pyrolusite and some forms of psilomelane. Braunite, though richer in manganese than either of these, contains much less available oxygen, and manganite is no better. The reason for this difference is due to the different stages of oxidation of the manganese in the different ores. They all consist of chemical combinations of manganese and oxygen, but braunite and manganite are in lower stages of oxidation, that is, the manganese in them is combined with less oxygen than in pyrolusite and psilomelane. Hence the manganese itself in braunite and manganite is higher than in the last two and, though they are of but little value as sources of oxygen, they are more valuable than pyrolusite and psilomelane as sources of metallic manganese.

Pyrolusite and psilomelane, when pure, are essentially com posed of peroxide of manganese, though psilomelane contains in addition small quantities of baryta and potash. The peroxide contains more available oxygen than any other oxides of manganese found in nature, and, as pyrolusite is a purer peroxide

than psilomelane, it is the most desirable ore for oxidizing purposes. The chemical composition of peroxide of manganese is a combination of one atom of manganese and two atoms of oxygen, amounting, when the ore is pure, to 63.2 per cent of manganese and 36.8 per cent of oxygen. Only one of the two atoms of oxygen, however, can be obtained economically, and therefore the amount of "available oxygen" in a theoretically pure ore is only 18.4 per cent. Even this is never found in commercial ores, as they are all more or less mixed with earthy impurities, and from 13 to 17 per cent is as high as they usually run.

The action of the ore in oxidizing processes.—Hence we see that when a manganese ore is employed as an oxidizer, the manganese itself is not utilized. It is simply the oxygen which is combined with the metal that is used, and the fact that manganese ore is adapted for such purposes depends upon the facility with which metallic manganese in nature combines with a large proportion of oxygen, and the equal facility with which it can be made to give up a part of that material. Hence, in the manufacture of chlorine, manganese is simply a carrier, as it were, to transport oxygen to the materials from which chlorine is extracted.

THE USE OF MANGANESE IN THE MANUFACTURE OF CHLORINE.

Requirements and valuation of the ore.—In the manufacture of chlorine, several other factors enter into the valuation of a manganese ore, besides the percentage of available oxygen. Any impurities soluble in hydrochloric acid are injurious, as they consume a part of that acid used in the process.* Iron, alkalies and alkaline earths come under this head. Ferrous oxide is additionally injurious as it not only uses up acid, but also absorbs oxygen. Carbonate of lime and other carbonates are also especially injurious as they both consume hydrochloric acid and give off carbonic acid, which has a very deleterious effect on the bleaching powder made from chlorine. In England ores containing over one per cent of carbonic acid are considered very poor for chlorine purposes.*

* Geo. Lunge, Manufacture Sulphuric Acid and Alkali, Vol. III.

The difficulty could be overcome by crushing the ore and treating it with acid, but this adds considerably to the expense. Even insoluble impurities, like sulphate of barium and silica, are undesirable, as they obstruct the action of the acid. The value of the ore also depends largely on its softness, as a soft ore is readily dissolved by hydrochloric acid, while hard ores require more heat, a longer time, and an excess of acid. Therefore many ores, otherwise very good, are rendered of but little value for the manufacture of chlorine by being too hard.

The ores are rated according to to their percentage of peroxide of manganese. The mineral pyrolusite, if theoretically pure, would be composed entirely of the peroxide, but, as found in nature, it always contains from 2 or 3 to 50 per cent or more of other ingredients. These are often in the forms of the various manganese ores which afford no available oxygen. According to Lunge* a deduction is made in England for German ores, used for chemical purposes, if they contain less than 60 per cent of peroxide, and an advance is given on any containing more than that. No German ores containing less than 57 per cent are accepted. The standard for Spanish and other similar ores is 70 per cent of peroxide, with an advance or a deduction for ores containing more or less. The minimum limit allowed is 65 per cent.

Nature, discovery and history of chlorine.—Chlorine is a greenish-yellow gas, of a pungent, suffocating smell, and, when exposed to a pressure of about four atmospheres, can be reduced to a yellow limpid fluid. It is one of the elementary substances composing the crust of the earth and forms an essential part of common salt. It was first discovered by Scheele, and was described by him in 1774. Previous to this, in the early part of the seventeenth century, the vapors which rise from aqua regia, and which are in part composed of chlorine, were known to Glauber and other chemists, but the nature of the material was not understood. Scheele discovered chlorine during his celebrated investigations on manganese, and his results have not only distinguished him as the first expositor of the nature of manganese compounds, but

* Geo. Lunge, Manufacture of Sulphuric Acid and Alkali, Vol. III.

also as the discoverer of a material which is today at the foundation of many of the most important manufacturing industries. Scheele noted the power of chlorine to bleach vegetable colors, a power on which depends most of its present uses, but its industrial value was first agitated by Berthollet* in 1785, and it was made at Javelle, near Paris, soon afterwards. James Watts introduced its manufacture into Glasgow in 1786. In 1798 and 1799 Charles Tennant made great improvement in its production, and started the practice of absorbing the gas in hydrate of lime. In the latter year, he erected the still celebrated St. Rollox Chemical Works at Glasgow for its manufacture.

Uses of chlorine.—As chlorine, under ordinary conditions, is a gaseous material, it is inconvenient to handle, and consequently it is passed into slaked lime, which absorbs it and forms the chloride of lime of commerce. This material is employed as an oxidizing agent in a vast number of industries, its principal use being in its bleaching powers, which are directly dependent upon its oxidizing qualities. It instantly destroys the strongest organic coloring principles, such as indigo and others, and its largest consumption is in bleaching vegetable fibre, such as cotton, flax, hemp, as well as manufactured cotton and linen articles, and old rags used in paper-making. Its next most extensive use is for disinfecting and deodorizing purposes; and in all sanitary work it is one of the most powerful agents available. It is also used as an oxidizer in dyeing and calico-printing, in the manufacture of chloroform and of chlorate of potash; in purifying spirits of wine and fusil oil; and in innumerable other industries where a powerful oxidizer is desired.

The manufacture of chlorine.—The simplest means of making chlorine is by treating pyrolusite with hydrochloric acid, but in former times the latter material was too expensive to allow of this being done profitably on a commercial scale, and therefore a process was resorted to by which pyrolusite and common salt were treated with sulphuric acid. The resulting products were sulphate of manganese, sulphate of soda, chlorine and water. The reaction which went on was :

* Geo. Lunge, Manufacture of Sulphuric Acid and Alkali. London, 1880.

MnO_2 (pyrolusite) + 2NaCl (salt) + $2H_2SO_4$ (sulphuric acid) = $MnSO_4$ (sulphate of manganese) + Na_2SO_4 (sulphate of soda) + 2Cl (chlorine) + $2H_2O$ (water).

This method was accompanied with considerable expense and is now only occasionally used to make chlorine in small quantities.

In the first half of this century, an extensive development of the alkali industry took place in England after the introduction of the Leblanc process from France, in 1824, and one of the waste products was hydrochloric acid. Consequently large quantities of that material became available, and its use in making chlorine quickly drove out the old method. It now practically supplies the whole of the chlorine * used for the making of bleaching powders, bleach-liquors, and the various other commercial forms of chlorine.

Many different ways have been used for treating the hydrochloric acid, but they all depend upon its action on pyrolusite, the peroxide of manganese. The acid attacks the ore and forms chloride of manganese, chlorine and water. The reaction which goes on is:

MnO_2 (pyrolusite) + 4HCl (hydrochloric acid) = $MnCl_2$ (chloride of manganese) + 2Cl (chlorine) + $2H_2O$ (water).

The process is carried on by treating coarsely ground pyrolusite in an oblong stone still with hydrochloric acid. At first the action goes on without the aid of heat, but after eight or ten hours it is hastened by injecting steam into the mixture at intervals of about an hour. The whole process takes about twenty-four hours. The chlorine is conducted off in pipes from the top of the still. The liquid that remains after the process is over, is known as "still-liquor" and contains chloride of manganese, together with a little chloride of iron and chlorides of other impurities that were in the ore; also a little free chlorine and hydrochloric acid.

Regeneration of manganese.—The still-liquor was formerly allowed to go to waste, doing great damage to the fish in the rivers, fouling the air and injuring anything that it came in con-

* Geo. Lunge, loc. cit.

tact with. Not only this, but all of the manganese was lost in the form of the chloride. As manganese ore was an expensive material, many efforts were made to save it and reconvert it to peroxide, so that it might be used over again.

Dunlop process.—No regenerating process was successful, however, until Charles Dunlop, in 1855, took out patents for the desired object. His process was introduced into the St. Rollox works and resulted in a great saving of expense, as the annual consumption of manganese at those works alone was then ten thousand tons. The method is as follows: The still-liquor is neutralized with ground chalk, the iron precipitated as hydroxide, and the rest of the liquor pumped into large, horizontal boilers, supplied with agitating shafts. More chalk is then added in quantities sufficient to combine with the chloride of manganese, and steam is blown in until a pressure of two to two and a half atmospheres is reached. In twenty-four hours, a chemical interchange between the chloride of manganese and the lime has taken place, resulting in the formation of chloride of lime and carbonate of manganese. The latter is removed, washed, pressed, partly dried and then placed in a furnace. Here it is gradually subjected to a heat which reaches a maximum of 315° C. A draft runs through the furnace and the manganese carbonate is occasionally splashed with water. At the end of twenty-four hours it has been completely oxidized. About 72 per cent of it is in the form of peroxide, the same form as pyrolusite, and 28 per cent is in the form of lower oxides of manganese and of lime, the latter comprising about 2 per cent.*

The peroxide thus prepared is said to be much more easily dissolved in hydrochloric acid than the native ore, and is therefore more serviceable in making chlorine.

Weldon process.—The Dunlop process is accompanied by considerable expense, and the method now almost universally used both in England and in Europe is the celebrated Weldon process, invented by Walter Weldon in 1867, and first put into practice at the works of Messrs. Gamble, at St. Helen's, in 1868. The principle of this method depends upon the fact

* Geo. Lunge, loc. cit., pp. 196-197.

that when freshly precipitated manganous hydroxide, in a solution of calcium chloride, and with an excess of lime, is subjected to a current of warm air, it is completely converted to manganese peroxide. The still-liquor is neutralized and freed from iron in the same way as in the last method. To it is then added 1.6 times the amount of milk of lime required to precipitate the chloride of manganese in the form of hydroxide. In this way a mixture of hydroxide of manganese, carbonate of lime and chloride of lime is obtained. This is heated by steam and a current of air passed through. The hydroxide is gradually oxidized to the peroxide and settles as a black sediment known as "manganese mud." The liquid is run off and the peroxide pressed into cakes. It is then ready to be used again in making chlorine.

This process has practically revolutionized the chlorine industry, saving, as it does, by far the larger part of the manganese There is always some loss, however, which has to be replaced by the addition of fresh manganese ore, but the total consumption of manganese for chlorine purposes has been very much reduced by the introduction of the Weldon process.

Consumption of manganese in the alkali trade in England.—The following figures are taken from tables quoted by Geo. Lunge. *

1852	12,000 tons.
1862	33,000 "
1876	18,200 "

The manganese represented in these statistics was largely consumed in the manufacture of chlorine, though smaller quantities were probably used for minor chemical purposes.

Source of chlorine supply in the United States.—Most all the chlorine used in the United States is imported. The reason for this is that in England, hydrochloric acid is obtained very cheaply, as a waste product from the alkali factories, while in this country, where comparatively little alkali is made, hydrochloric acid is much more expensive. Consequently, competition is at present impossible. In England the alkali and chlorine

* Manufacture of Sulphuric Acid and Alkali, Vol. III., pp. 67-70:

manufactures are carried on together, and it is the profits realized from the chlorine, that make it possible to sell the alkali at the present low rates.

THE USE OF MANGANESE IN THE MANUFACTURE OF BROMINE.

The use of manganese in the manufacture of bromine depends on the same principles as its use in the manufacture of chlorine. In fact, the process which goes on is the generation of chlorine, from hydrochloric acid or from chlorides by means of peroxide of manganese, in the manner already described, and the action of this chlorine on various bromides, causing the evolution of bromine.

The nature of bromine.—Bromine was discovered by Balard in 1826. At ordinary temperatures it is a deep red, very volatile, thin liquid, with a suffocating and very pungent odor. It goes off in yellowish-red fumes when heated and has a bleaching power similar to that of chlorine. It is used in photography, medicine, aniline dyes, as a reagent in chemical work, and in limited quantities for various other purposes, but its application is much less extensive and less varied than that of chlorine, and its production is correspondingly small.

The sources of bromine.—Bromine is a constant constituent of sea water, and frequently occurs in saline springs, and in salt deposits. From these three sources the principal supply of it is obtained. It is genarally found in the form of bromide of magnesium, sodium, potassium or lime and its preparation consists in its extraction from these compounds.

The manufacture of bromine in the United States.—The manufacture of bromine on a large scale in the United States was begun at Natrona, in Pennsylvania, in 1868, and spread thence to Pittsburg, and to Pomeroy, and other places in the valley of the Ohio River in Ohio and West Virginia. It is at present made from the mother-liquor obtained from salt brine. The brine is partly evaporated and the larger part of the salt deposited. The remaining liquor contains the salt that was not deposited and the soluble bromide. Sulphuric acid and peroxide of manganese (pyrolusite) are added to this solution. The sulphuric

acid acts upon the salt (chloride of sodium) forming sulphate of sodium and hydrochloric acid. The latter attacks the oxide of manganese forming chloride of manganese and chlorine. The chlorine attacks the bromide forming chloride of sodium and setting free the bromine. The latter is then distilled over and condensed.

The manufacture of bromine at Stassfurt, Saxony.—Large quantities of bromine are obtained from the salt springs of Stassfurt, in Saxony. The bromine here occurs in the form of bromide of magnesium and was first worked on a large scale by A. Frank, in 1865. Most of the salts of soda and potash are removed from the brine by concentration, and it is then treated with chlorine, as already explained. The still is heated and the bromine is distilled over and condensed.* The various processes in the manufacture of bromine in Europe have been fully described by Dr. Emil Pfeiffer.†

The manufacture of bromine in Scotland.—In Scotland ‡ large quantities of bromine are obtained from the mother-liquor of varec. Varec is the alkaline residue obtained by burning seaweed, and is used as a source of alkali. The process of extracting the bromine is the same general method as that described last. The principal difference is that the solution contains iodine, which has to be removed before the bromine is extracted. This is done either by precipitation by passing chlorine through or by adding sulphate of copper and forming iodide of copper and free iodine.||

THE USE OF MANGANESE IN THE MANUFACTURE OF GLASS.

Effect.—Manganese is used to accomplish two different results in the manufacture of glass: one in removing the green color given by iron and the other in giving a violet, amber, or black color.

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* Spon's Encyclopedia of the Industrial Arts, Manufactures and Commercial Products, Division II., p. 542.

† "Handbuch der Kali-Industrie, Braunschweig, 1887.

‡ Spon, loc. cit., p. 542.

|| Spon, loc. cit., p. 543.

As a decolorizer of glass.—One of the most important points in selecting sand and other material for glass-making is to have them as free as can be from iron impurities, but it is practically impossible to get them absolutely pure and the presence of iron shows itself in the green color common in bottle-glass. This color is due to the existence of iron in the ferrous state, or state of low oxidation, and is removed if pyrolusite (peroxide of manganese) is mixed in with the glass during its manufacture. The manner in which the pyrolusite effects this is a somewhat disputed question. Two explanations have been given: the first is that the peroxide of manganese gives up a part of its oxygen to the ferrous iron and converts it to the ferric state, or state of high oxidation. In this form the iron, when in small quantities in the glass, gives a light lemon-yellow color which is almost imperceptible, and hence the clearness of the glass. The second explanation is that the green color of the iron and the purple, which, under certain conditions is given by manganese, act as complementary colors, neutralizing each other and giving a colorless glass. It has also been suggested that a combination of both actions goes on, by which a part of the ferrous iron is oxidized to ferric iron and the greenish-yellow of the latter is neutralized by the purple of the manganese.

If sufficient heat is not used, the manganese is apt to give a pink or violet color to the glass, and the same effect is produced if too much manganese is used. Hence, if perfectly clear glass is wanted, these contingencies must be guarded against. Even when a colorless glass is obtained, the long continued action of sunlight on it very often brings out the violet color, and hence the cause of that color often seen in the window-panes of many old houses. To avoid these difficulties, arsenic trioxide is often used instead of manganese peroxide and for the same purpose. When heated with the glass, it gives up its oxygen to the ferrous oxide, and the arsenic is volatilized, and thus entirely removed from the glass.

Another difficulty with the use of manganese peroxide is that, as found in nature, it almost invariably contains more or less iron, which, of course, is injurious to the glass. Therefore

pure peroxide is often chemically prepared by dissolving the ore, freeing it from iron and reconverting it to peroxide.

*As a coloring material in glass.**—In coloring glass, a pink or violet shade can be gotten, as already shown, by adding manganese, which forms a silicate with the glass. If the glass is heated too long or too high, however, the color disappears. A red color can be obtained in glass by adding certain mixtures of manganese peroxide and iron sesquioxide. A black or dark amber color can also be gotten by proper treatment of the glass with manganese oxides.

THE USE OF MANGANESE AS A DRYER IN VARNISHES AND PAINTS.

Manganese peroxide is used as a dryer in oils to be mixed with varnishes and paints. The oxide is not left permanently in the oil, but is only immersed in it for a certain length of time, when it is removed and, after exposure to the air, is ready to be used again. Its effect is to materially increase the power of the oil to dry rapidly. It is claimed that this result is reached by the manganese giving up part of its oxygen to the oil, and that on exposure to the air the manganese replaces its lost oxygen by a new supply from the atmosphere. It seems somewhat doubtful whether this transmission of chemically combined oxygen actually takes place, and whether the manganese oxide does not benefit the oil by simply carrying to it oxygen from the air mechanically held in its interstices.

Sometimes manganese peroxide is not used in the raw state in oil, but is prepared chemically. In this condition it is said to be especially fitted for a dryer. Oxide of lead is sometimes used for the same purpose.

THE USE OF MANGANESE IN ELECTRICITY.

Leclanche's battery.—Pyrolusite (peroxide of manganese) is used as one of the elements in Leclanche's battery.

The production of electricity in batteries depends on the

* The mention of the use of manganese in coloring glass belongs properly under the heading of the uses of manganese for coloring materials, but it is given here in order to bring all the applications of manganese in glass-making together.

fact that when two metals, immersed in a liquid medium which dissolves one more easily than the other, are connected together, a current is generated, proceeding from the more soluble to the less soluble metal. The more soluble metal represents the negative pole or electrode of the battery, and is usually made of zinc; the less soluble metal represents the positive pole or electrode, and is often made of copper. An entirely insoluble material may be used for the positive pole, and carbon or platinum are frequently employed. The liquid medium in the battery is usually water with sulphuric acid or some other material that will attack the soluble pole.

During the generation of the electricity, the acid attacks the zinc forming a soluble sulphate of zinc, or other salts of that metal, varying according to the liquid used. Hydrogen is liberated from the dilute acid and settles, when there is nothing present to take it up, on the positive pole. It also attacks the soluble salt of zinc, reducing it to the metallic state and causing the formation of a layer of zinc on the same pole. Both these effects of hydrogen weaken the action between the two metals, and the current becomes correspondingly weak. This is known as the polarization of the electrodes, and is usually counteracted by the addition of a material which acts chemically on the hydrogen and prevents its remaining on the pole. In the Daniell's cell, and also in the Gravity battery which is almost universally used for telegraph work in this country, the required material is supplied in the form of sulphate of copper (blue vitrol); in Leclance's battery it is supplied by peroxide of manganese (pyrolusite).

In Leclanche's battery, the negative pole is zinc. The positive pole is a carbon rod tightly packed in a porous jar with a mixture of equal parts of coarsely ground pyrolusite and carbon. The top of this mixture is covered over by a layer of pitch. Both the zinc and the porous jar, with its contents, are immersed in an aqueous solution of chloride of ammonium (sal-ammoniac), which plays the part of the dissolving medium. When the circuit is closed, the chloride of ammonium, zinc and water react on each other, forming chloride of zinc and hydrate of ammonium,

and evolving hydrogen from the decomposition of the water. The hydrogen thus set free combines with a part of the oxygen in the pyrolusite and is again converted to water, instead of being deposited on the pole. The pyrolusite is reduced from the peroxide state to a lower stage of oxidation and has be to renewed at intervals. A modification of the carbon electrode has been introduced in the form of a mixture of finely ground pyrolusite and carbon pressed into a brick. By this arrangement, no porous jar and no additional manganese and carbon packing is required.

The electromotive force of Laclanche's cell, when first started, is 1.38, compared with that of the Daniell's cell as a unit; and Leclanche states that 24 of his cells can replace 40 Daniell's cells.* This amount of power is due to the depolarizing action of the peroxide of manganese, and renders Leclanche's cell, for certain purposes, more useful than the Daniell's cell. In continuous work, however, the Leclanche cell soon becomes polarized and loses strength, but it rapidly regains its power when left at rest for a short time. Hence the cell is not adapted for long continuous service, such as heavy telegraphic work; but is excellently fitted, by reason of its quick recovery, for open circuit work, such as in telephones, electric bells, etc. For these purposes it is very extensively used all over the United States.

THE USE OF MANGANESE IN THE PREPARATION OF OXYGEN.

A common method of preparing oxygen on a small scale is to heat pyrolusite (peroxide of manganese) to redness in a retort. The pyrolusite gives off part of its oxygen and goes into a lower oxide. The oxygen is conducted through a tube into a receiving vessel. As already explained, the power of pyrolusite to give off oxygen in this manner depends on its high degree of oxidation, a property which is also shared by psilomelane. But on account of the greater hardness of the latter ore, as well as its usual contents of other materials with the peroxide of manganese, the amount of oxygen obtainable from it is usually less than from pyrolusite.

* Electric Batteries, Alfred Niaudet, translated by L. Fishback, 1888, p. 183.

Oxygen is often made by heating chlorate of potash in a retort or flask. The chlorate is decomposed with the formation of oxygen and chloride of potassium. It is found that if finely powdered oxide of manganese is mixed with the chlorate of potash, the latter gives off its oxygen much more readily and at a much lower temperature than if heated alone. At the same time the oxide of manganese is in no way affected, none of its oxygen is removed and all of that gas which is produced comes from the chlorate. This is a case of the influence occasionly seen in chemical reactions, which some substances can exert in certain processes without undergoing any apparent change themselves.

Both those methods of obtaining oxygen are only used on a small scale.

THE USE OF MANGANESE IN DISINFECTANTS.

Manganese, in the form of manganates, and permanganates is extensively used for disinfecting purposes. These materials include two series of salts, representing two acids high in oxygen, known as manganic ($H_2 MnO_4$) and permanganic ($HMnO_4$) acids. The manganates are less highly oxidized than the permanganates, but are very unstable and readily pass into the latter form. This transition can be brought about by the action of carbonic acid or by dissolving in an excess of water. Conversely, the permanganates can be converted to the manganates by boiling in strong caustic potash or by the action of a reducing agent. The manganates are characterized by a green color, and their solutions, unless in the presence of a large excess of free alkali, assume a violet or red color and pass into the permanganates. This very markedc hange in color led Scheele to give the coloring material the name of mineral chameleon, a name also applied to other mineral substances.

When the manganates or permanganates are brought in contact with organic matter, they readily decompose and give up part of their oxygen. On this fact depends their use as disinfectants. The oxygen combines with, and carries off the injurious elements in the decaying material. Both series of salts

are also used for other oxidizing purposes, in laboratory work, in bleaching fats and in other ways.

Permanganate of potash is the most common of the permanganate or manganate compounds, and has long been used as a powerful oxidizing agent in various chemical reactions. The use of manganates and permanganates as disinfectants, however, was not introduced until after Hofmann, in 1859, had pointed out their value in sanitary work. H. B. Condy, of London, was the first to bring about their extensive use, and, in 1862, he received a prize medal for their manufacture on a large scale. The green and red liquids known as Condy's Fluids are alkaline manganates and permanganates. The compounds ordinarily used for sanitary purposes are mixtures of manganate and permanganate of sodium. They are made by heating to a dull redness, for forty-eight hours, in a flat vessel, a mixture of caustic soda and finely divided peroxide of manganese (pyrolusite). * This is then lixiviated and partly boiled down. It can be used in this fluid form, or evaporated and shipped as solid.

If it is desired to get pure permanganate free from manganate, the latter is converted into the former, by neutralizing the solution with sulphuric acid, concentrating until Glauber's salt (sulphate of sodium) crystallizes out, removing this and further evaporating the solution. †

THE USE OF MANGANESE IN CALICO-PRINTING AND DYEING.

In calico-printing and dyeing, manganese compounds can be used both as coloring materials and as mordants.

Manganese as a coloring material.—The color known as "manganese brown" or "manganese-bronze" can be obtained by the use of the chloride, sulphate or acetate of manganese. What is known as "bronze liquor" is a solution of chloride of manganese; but a solution of the acetate is preferable as the acid properties of the former are apt to injure the fabric. The cloth is treated with a solution of whichever salt of manganese is used and then with soda-ash or lime, thus forming the protoxide of

* Roscoe and Schorlemmer, Treatise on Chemistry, Vol. II., Part II., page 23.

† Hofmann's Report, Exhib., 1862, p. 109. (cited by Roscoe and Schorlemmer).

manganese, which is precipitated in the cloth. This material is white when freshly formed, but, by exposing to the air, or by treating with chloride of lime, it goes into a higher oxide, which has the desired brown color. Figures in different colors can be printed on the "manganese brown" ground, the colors being so composed as to remove the brown immediately under them, thus giving white, black, blue, red, yellow and other colored objects on a brown background. This is known as "manganese bronze style". *

If cotton is soaked in a solution of permanganate of potash it assumes a dark brown color similar to that already described.

Manganese as a mordant.—Manganese in the form of the hydrated protoxide is sometimes used as a mordant in "fixing" different colors in dyeing. The fabric to be dyed is treated with permanganate of potash and then subjected to the action of a strong reducing agent. This causes the precipitation of the hydrated protoxide in the fibre, which is then ready to receive and hold the required dye.

THE USE OF MANGANESE IN COLORING GLASS, POTTERY, BRICKS AND OTHER MATERIALS.

The use of manganese in coloring glass has already been described under its use in decolorizing the same material. Pottery and earthenware are sometimes colored by manganese in a similar manner to glass. A jet black can be given to door knobs † by manganese oxide; and other colors are produced in the glaze of pottery. The pottery known as Rockingham-ware is colored a deep brown or almost black by adding manganese to the glaze. ‡ A lead-gray tint can be gotten by the use of manganese alone, and variously shaded brown colors can be obtained with mixtures of manganese and iron.

Wad and other low grade earthy manganese ores are used in

* Spon's Encyclopedia of the Industrial Arts, Manufactures and Commercial Products, Division III., p. 852.

† Geological Survey of Ohio, Vol. V., Economic Geology, p. 677.

‡ Geological Survey of Ohio, Economic Geology, Vol. V., p. 682.

giving a rich, dark, chocolate-brown color to the bricks, and in coloring artificial brownstone.

The oxides of manganese are also used for coloring mottled soap.

THE USE OF MANGANESE IN PAINTS.

The manganese ore known as wad is used in its crude state as a pigment, varying in color from a dark-chocolate to a reddish-brown. Manganese, in a manufactured form, has also been used for paints of various other colors, but especially green.

Manganese green.—This is made by mixing three to four parts of caustic baryta, moistened with water, with two parts of nitrate of baryta and two parts of oxide of manganese, placing in a crucible, previously heated to dull redness, and then fusing. The product thus obtained is poured out, pulverized, digested in boiling water, washed in cold water and dried in an atmosphere free from carbonic acid.* This material is a barium manganate and has been recommended for use in place of the color known as "Scheele's Green", which contains arsenic and is very poisonous. "Nurenburg Violet" is also made of manganese compounds.

OTHER USES OF MANGANESE BESIDES THOSE DESCRIBED.

Besides the various uses of manganese already mentioned there are many others, which, though they consume insignificant quantities of ore are very necessary for medical, chemical and manufacturing purposes. Sulphate of manganese is frequently used in medicine. The oxide, sulphate, chloride, and as already stated, the manganates and permanganates, as well as other salts of manganese serve many purposes in work in chemical laboratories and in small quantities in various arts other than those already mentioned.

The finer varieties of rhodonite or silicate of manganese are of a beautiful pink color and are frequently used as ornamental stones or cut for gems.

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* Spon, loc. cit., Division V., page 1549.

Map showing
the distribution of
MANGANESE DEPOSITS
(EXCLUSIVE OF MANGANIFEROUS IRON ORES AND MANGANIFEROUS SILVER ORES)
IN
THE UNITED STATES, CANADA AND CUBA.
To accompany Volume I of the
ANNUAL REPORT OF THE
GEOLOGICAL SURVEY OF ARKANSAS
for 1890.
John C. Branner, State Geologist
R.A.F. Penrose Jr, Assist. Geologist
* Areas from which ore has been shipped.
+ Areas from which practically no ore has been shipped.
CANADA
MEXICO
BAHAMA ISLANDS
SAN DOMINGO
JAMAICA
85°
80°
75°
70°
65°
60°
55°
45°
40°
35°
30°
25°
20°

PACIFIC
NEW MEXICO
NEVADA
MONTANA
DAKOTA
SOUTH
DAKOTA
MINNESOTA
115°
110°
105°
100°
95°
120°
125°
130°
35°
40°
45°
50°

CHAPTER IV.

THE MANGANESE INDUSTRY.

HISTORY OF MANGANESE MINING IN THE UNITED STATES AND CANADA.

General Statement.—Manganese was mined in the United States as early as 1837, but the production at that time was very insignificant, and it was not until 1867 to 1869 that any systematic attempts were made to work the American ores. In Canada, the first mining was done in 1861, and the largest production, up to 1888, was that of the year 1880, which amounted to 2,179 short tons. The production of the United States, even as late as 1880, was small, amounting in that year to about 5,761 tons. Since 1880, however, the production has increased considerably, amounting in 1888 to 29,198 tons.*

In the United States, manganese ores have been mined in Vermont, New Jersey, Virginia, Tennessee, North and South Carolina, Georgia, Alabama, Arkansas, Colorado, California, and other states in small quantities. Manganese ores exist in Texas, but have not been worked. In Canada, manganese has been mined for many years in the Provinces of Nova Scotia and New Brunswick, with smaller quantities in Quebec.

Of all these localities, the only ones now producing manganese as a regular industry are New Jersey, Virginia, Georgia, Arkansas, Colorado, California, Nova Scotia, and New Brunswick. Of these, Virginia, Georgia and Arkansas produce over nine-tenths of the total output of North America.

* The figures given for the production in the United States do not include manganiferous iron ores nor the manganiferous silver and zinc ores.

Early manganese mining in the United States: Tennessee, 1837; Arkansas, 1850–52.—The first manganese ore mined in the United States, so far as the writer has been able to find out, was obtained near Whitfield, Hickman County, Tennessee, in 1837. This locality was worked on a very small scale, and limited quantities of ore have been taken out at various times since then for use in coloring earthenware. The production has always been very insignificant and that of 1885 was only a few hundred pounds.* The next manganese mining on record was in the Batesville region of Arkansas, between 1850–52, when Col. Matt. Martin shipped small quantities of ore from that locality. Similar limited quantities were mined occasionally for some thirty years, but the quantity was very small, and the first large shipments from Arkansas date from 1881.

Virginia, 1859.—In 1859 Mr. Sibert† prospected and opened up several localities in the Valley of Virginia, among which were the Lyndhurst and the Kennedy mines. Small quantities of ore were taken out but work seems to have been soon discontinued. There are frequent statements of so-called "large quantities" of manganese ore having been mined in several other places in Virginia about this time, but it seems more probable that a part of this, at least, was manganiferous iron ore, and that the production of manganese ore, properly so-called, was very limited.

Up to this time the small amount of manganese mined in the United States was of very little importance. The subject had not yet attracted general interest, as the demand for the ore in this country was still very small; the annual consumption probably did not exceed a few hundred tons, and this was largely supplied from European sources. Even in England, the consumption was limited and Prof. J. D. Whitney,‡ writing in 1854, states that Nassau then supplied all the wants. In 1852, 3,291 tons were imported into Liverpool from that locality and sold at 8*l* sterling per ton.

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* Mineral Resources of the United States, 1885, pp. 344-345.

† Ibid, p. 317.

‡ Mineral Wealth of the United States 1854.

Vermont, 1859.—About the time Sibert was prospecting in Virginia, or possibly a little earlier, manganese mining began in Vermont. The exact year that work was commenced is uncertain, but in the Geology of Vermont, † published in 1861, it is stated that considerable quantities had already been shipped to England from Brandon and Chittenden in that state. The writer is informed by Dr. Prime, of Brandon, that the deposits of that neighborhood were worked for iron ore about seventy-five years ago, but the manganese was avoided, as it was thought to be injurious to the iron, and it was not worked until something over thirty years ago, before 1860.

Nova Scotia and New Brunswick, 1861–1890.—In 1862 the Tenny Cape Mine, of Nova Scotia, was opened, and this represented the first systematic work done on Canadian manganese, though small quantities had been obtained in 1861. About 1864, the first work was done in New Brunswick, at the Markhamville mines, under the management of Major A. Markham. Major Markham has been a most active worker in developing the ores of that region, and practically the whole production of New Brunswick manganese now comes from the Markhamville mines. Other mines in Canada have since been opened up and worked to a greater or less extent, such as at Cheverie, Walton, Loch Lomond (Cape Breton), and elsewhere in Nova Scotia; Shepody Mountain, Jordan Mountain, and Quaco Head and other places in New Brunswick.

James E. Mills, in Virginia and elsewhere, 1867–1871.—Mr. James E. Mills, in 1867, was the first to undertake a systematic search for manganese in the United States. In the interests of a firm in Newcastle, England, he visited many localities in New England, the Middle States, the Valley of Virginia and elsewhere, collecting all the information that was available on the subject. This, however, was very small, as is shown by his statement made in a paper written in 1871, in which he says, "The consumption of manganese in this country is quite limited, and it is perhaps principally on this account that so little is known

† E. Hitchcock, E. Hitchcock, Jr., A. D. Hager and C. H. Hitchcock, published by authority of the State, 1861.

of the deposits of the ore on our own territory, the greater part of the little consumed being imported from Nova Scotia and elsewhere. If the manufacture of bleaching powder were undertaken, or any metallurgical process which required considerable quantities of the binoxide of manganese, it would be a serious question where to obtain it cheaply and in the required amounts."

Mr. Mills early predicted the value of the Virginia ores and opened up the Cabell mine in the valley of the James River, in that state. He mined over 4,500 tons of manganese ore, which was sent to England for use in the manufacture of chlorine. This use at that time represented the principal consumption of manganese, and as nearly all of the chlorine used in the United States was made in England, the larger part of the manganese ore was sent there. A very pure peroxide or pyrolusite was required for this purpose, and, as the pyrolusite of Virginia was generally associated with greater or less quantities of other oxides, the production of that state was not large. The use in steel, however, was beginning to make itself more strongly felt than in former years, and its requirements soon began to reach large proportions.

Virginia, Georgia and California, 1867.—The year 1867 seems to have marked an era in manganese mining in the United States. Not only were Mr. Mills' investigations started in that year, but the Crimora mine of Virginia, and the Dobbins mine of Georgia, the first manganese mine in that state, were opened shortly afterward. In the same year also the Old Ladd mine in Corral Hollow, San Joaquin County, California, and Red Rock island in the Bay of San Francisco were worked for the first time. In Georgia, however, about 550 tons of ore are said to have been mined in 1866.*

Crimora mine, Virginia, 1867-1888.—The Crimora mine was worked by a stock company from 1867 until 1869, when operations were suspended, and from then until 1882 only occasional small quantities of ore were mined. In that year it was leased by Jas. B. White and Company, of Pittsburg, and operation on a large scale were begun. It is now operated by

* Mineral Resources of the United States, 1885, p. 329.

the American Manganese Company. It has produced more manganese than any other mine in the United States, and its total production represents the larger part of that of the whole of Virginia, since the time manganese mining was begun in that state. Up to December 31st, 1888, the total output of the Crimora mine was about 103,785 tons.*

Virginia, Georgia and other Eastern States, 1867-1890.—In both Virginia and Georgia, numerous other manganese mines have been opened since 1867, such as the Bagley, Mt. Athos, Midvale, Simpson, Davis and other localities in Virginia, and the Chumler Hill, Bishop, Poorhouse, Layton and Satterfield properties in the Cartersville region of Georgia; the Banks, Ware and other properties in the Cave Spring region of Georgia, and the Tunnel Hill mine in the extreme northwest corner of the same state. Manganese has also been mined in Pennsylvania, Maryland, Tennessee, North and South Carolina, and Alabama, but the production has been very small. The total yearly output of Virginia and Georgia has grown very considerably since 1867, but the production of individual localities has been very irregular, and has been characterized by alternating, spasmodic increases and decreases, due largely to the uncertain character of the deposits. The total production of the two states in 1888 was 23,214 tons.

California, 1867-1882.—The first manganese mining in California, as already stated, was done in 1867 at the Old Ladd mine in San Joaquin County, and on Red Rock island in the Bay of San Francisco. The Old Ladd mine has produced most of the manganese of that state. It was opened by A. S. Ladd and worked by him until 1874, during which time he shipped about five thousand tons of ore. This, as well as the production of Red Rock, was almost all sent to England. There appears to be some doubt as to the production of the Red Rock locality but it was very much smaller than that of the Old Ladd mine. It is stated that at least one schooner load, and probably more, had been shipped when the mining was stopped by the government authorities, who wished to preserve the island for harbor pur-

* Mineral Resources of the United States, 1888 p. 133.

poses. In 1874, the Old Ladd Mine was bought by Justinian Caire, of San Francisco. About 1875 the shipments of California ore to England were stopped by the impossibility of competing with Spanish manganese; and since then, only very small quantities have been produced in that state. Mr. Caire still owns the Old Ladd mine and maintains a small annual production for use in his chemical manufactures in San Francisco and to supply the limited demand of California. In 1882 work was started on small deposits near Saucelito, Marin county, California, in the mountains forming the northern barrier of the Golden Gate of the Bay of San Francisco. The production was used as a flux in a smelter at Saucelito. Only small quantities were mined, and work has since been abandoned. Manganese ore is also said to have been mined in Santa Clara county, California, but no details are available and no work is being done now.

Arkansas, 1850-1890.—In the meantime, Arkansas had come on the scene as a considerable producer of manganese ore. As already stated, Col. Matt. Martin made small shipments of manganese from the Batesville region in that state as early as 1850-1852, but the quantity mined was very small. The first shipment from Arkansas, for use in the manufacture of steel, was made by Wm. Einstein, of St. Louis, who, in 1868, sent about ten tons to Messrs. Schoenberger and Company, Juniata Iron Works, Pittsburg, Pa. Though the test of the ore is said to have been satisfactory, shipments were not continued; and it was not until 1881, when Mr. E. H. Woodward, representing the Ferro-Manganese Company, appeared on the scene, that Arkansas became a regular producer of the ore. Mr. Woodward had already had large experience in the manganese region of the Appalachian Mountains, and was one of the first to open up the deposits in the neighborhood of Cartersville, Georgia. In Arkansas, he worked the Southern Hill, the Turner, Trent, Montgomery and other mines in the Batesville region, and is said to have shipped some five thousand tons of manganese up to 1887.

In 1885, the Keystone Iron and Manganese Company, of Pennsylvania, commenced operations on the Southern Hill, near Cushman, in the Batesville region, and at once became the largest

producers of manganese in the state. Their production up to December 1st, 1890, has been 18,111 tons of ore. In the same year, 1885, The St. Louis Manganese Company and the Missouri Furnace Company, both of St. Louis, Missouri, acquired manganese lands in the Batesville region. Their production up to September, 1890, has been 1700 tons and 500 tons respectively.

In 1888, Messrs. Abbot and Ring, of Chicago, carried on operations north of Batesville. The firm was later changed to Skinner and Abbot, and then to John B. Skinner and Company. Their production from June 20, 1889, up to June 26, 1890, was over 700 tons.

The Keystone Iron and Manganese Company, and John B. Skinner and Company are now (December 1st 1890) the principal operators in the Batesville region. Other companies, as well as numerous private individuals, have also shipped ore from the same district, and further details are given in the description of the Batesville region. The total production of this region up to December 31st, 1890, has been between thirty and thirty-five thousand tons, and probably nearer the former figures.

In 1888, work was begun by the Arkansas Improvement Company on the manganese ores of Polk and Montgomery counties, in south-western Arkansas. About twenty tons are said to have been mined. Work was discontinued in April, 1889. About the same time limited mining was done by the Capitol Land and Mining Company in what is known as the Fletcher Range, in Pulaski county, twelve miles west of the city of Little Rock. No quantity of ore was shipped and operations here also have been abandoned.

New Jersey, 1870–1890—Manganiferous zinc ores are found at Sterling Hill and Franklin, Sussex county, New Jersey. The residue from these ores after the extraction of the zinc was used, in 1870, in the manufacture of the first spiegeleisen ever made in the United States. It is still used for the same purpose.

Missouri—Manganese and manganiferous iron ores are found in several places in the vicinity of Pilot Knob in the south-

eastern part of Missouri *, and have been worked to a limited extent in Iron county, on the land of Mr. Marble at the Culbertson Bank, at Buford Mountain and elsewhere. Manganese ore has also been found near Arcadia in the same county.

Texas.—In Texas, manganese ore has been found in Llano and Mason counties, in the central part of the state, but it is still about sixty miles from a railway and none has yet been shipped.

Nevada.—In Nevada, manganese has been found near Golconda, on the Central Pacific Railroad, in the valley of the Humboldt River. 13½ tons are said to have been shipped a few years ago to San Francisco. The deposit is small and is not worked at present.

Colorado.—In Colorado, manganese has been found in several parts of Gunnison county, but most of the localities are at present too far from railway transportation to be of immediate value. A manganiferous iron ore, however, which forms the gangue of many silver-bearing veins especially of the Leadville district, has been introduced, in the last few years, at Pueblo, Colorado, as a source of spiegeleisen and ferro-manganese. It is at present used for these purposes at the works of the Colorado Coal and Iron Company at that place. The first shipment of this ore, to points east of the Mississippi, was made in the summer of 1890, when 500 tons were sent to the Illinois Steel Company, of Chicago.

Montana and Arizona.—A manganiferous gangue is also found with the silver ores at Butte City, Montana; at Tombstone Arizona, and in lesser quantities elsewhere in the Rocky Mountains and the West; but Colorado is the only place in that region where the gangue material has been used as a source of metallic manganese.

PRODUCTION OF MANGANESE ORES IN THE UNITED STATES.

In the annual reports of the Mineral Resources of the United States those ores only are included as manganese ores which contain over 44½ per cent of metallic manganese. Many manganiferous iron ores are found containing less than 44½ per

* Raphael Pumpelly, Geological Survey of Missouri, Iron Ores and Coal Fields, 1872.

cent of manganese, but these are grouped as a separate class. Manganiferous silver ores are also classed separately. The production in tons of manganese ores proper, as thus limited, in the United States from 1880 to 1888 was:

Production of manganese ores in the United States, 1880–1888.*

STATE.	1880	1881	1882	1883	1884	1885	1886	1887	1888
Virginia	3,661	3,295	2,982	5,355	8,980	18,745	20,567	19,835	17,646
Arkansas	.....	100	175	400	800	1,483	3,316	5,651	4,312
Georgia	1,800	1,200	1,000	.....	.....	2,580	6,041	9,024	5,568
Other States	300	300	375	400	400	450	269	14	1,672
Total	5,761	4,895	4,532	6,155	10,180	23,258	30,193	34,524	29,198

The production of manganese ores in the United States previous to 1880 is very uncertain, but the following table will give an approximation:

Production of manganese ores in the United States, 1837–1879.†

STATE.	YEARS.	TONS.
Virginia	1867 to 1879	18,000.
Georgia	1866 to 1879	19,950.
Arkansas	1838 to 1879	Probably a few hundred tons.
Vermont	..... ?	.....
California	1867 to 1875	Probably 5,000 to 6,000.
Other States	1837 to 1879	Very little.

The total production of the United States from 1837 to 1879 inclusive, would probably not amount to much, if any, over fifty thousand tons. Further statistics of different states and of individual localities are given under the descriptions of those places.

* Mineral Resources of the United States, 1888, p. 125.

† Compiled from the Mineral Resources of the United States and all other available sources of information.

Production of manganese ores and the richer of the manganiferous iron ores in the United States, 1888.*

STATE.	Production in tons.	Total value at mines.	Average value per long ton.
Virginia	17,646	$ 171,848	$ 9 74
Michigan	11,562	37,000	3 20
Georgia	5,568	38,126	6 85
Arkansas	4,312	38,582	8 95
California	1,500	†30,000	20 00
Vermont	1,000	5,500	5 50
North Carolina	50	150	3 00
South Carolina	50	150	3 00
Pennsylvania	22	225	1 00
Nevada	20	80	4 00
Tennessee	16	48	3 00
Total	41,746	$ 321,709	$ 7 70

Of the above production, most of that from Virginia was manganese ore proper, though a small part of it was manganiferous iron ore. Of the Michigan product all except 100 tons was manganiferous iron ore, containing about 11 per cent of manganese. The 100 tons was high grade manganese ore. All the Michigan production came from the Gogebic range, in the Lake Superior region, and mostly from the Colby mine. Most of the Georgia production, as well as all of that of Arkansas and California, was manganese ore. Most of that from Vermont was manganiferous iron ore. The product from Pennsylvania is said to have been classed as manganese ore, though the price quoted would suggest a low grade material. The product from the other states mentioned is said to have been more or less mixed with iron.

* Mineral Resources of the United States, 1888, p. 124.

† Value at San Francisco.

PRODUCTION OF MANGANIFEROUS IRON ORES IN THE UNITED STATES.

Some of the richer manganiferous iron ores are included in the manganese productions for 1888 given in the above table, and are mentioned in the explanation which accompanies it. Large quantities of ore, however, are mined which are considerably lower in manganese. The principal sources of them is the Gogebic range, Lake Superior region, Michigan. The following table gives the production of that region.* Most of the ore came from the Colby mine.

Production of manganiferous iron ores in Michigan, 1886–1888.

	1886	1887	1888
Ore containing between 10 and 11 per cent of manganese	.....	10,000	† 11,462
Ore containing between 2 and 4 per cent of manganese	257,000	200,000	189,574

Production of manganiferous iron ores in Virginia, Georgia, Vermont and Maine, 1887.

STATE.	TONS.
Virginia	1,025
Georgia	195
Vermont	481
Maine	50

In 1888 about one thousand tons of manganiferous iron ore were produced in Vermont.

PRODUCTION OF MANGANIFEROUS SILVER ORES IN THE UNITED STATES.

The production of manganiferous silver ores in the United States is derived almost entirely from the Rocky Mountain region, with small quantities from elsewhere in the western states. These ores are worked for the silver they contain. None are used as a source of manganese except in the case of certain mines

* Compiled from figures given in the Mineral Resources of the United States for 1886 1887, and 1888.

† The Colby mine also produced one hundred tons of manganese ore proper, which is not included here, but is represented in the last table.

at Leadville and elsewhere in Colorado, where a manganiferous iron ore gangue is found and used as a source of spiegeleisen.

Production and value of manganiferous silver ores in the Rocky Mountains, 1882–1888.

YEAR.	LOCALITY	TONS.	VALUE.
1885	From Montana alone	4,263	
1886	From the whole Rocky Mountain region	60,000	$ 600,000
1887	From the whole Rocky Mountain region	60,000	$ 600,000
1888	From the whole Rocky Mountain region	60,000	$ 600,000

SUMMARIZED PRODUCTION.

Production and value of manganese ores, manganiferous iron ores and manganiferous silver ores in the United States, 1886–1888.*

KIND OF ORE.	1886		1887		1888	
	Production	Value.	Production.	Value.	Production.	Value.
Manganese ores	30,193	$277,636	34,524	$333,844	29,198	$279,416
Manganiferous iron ores	257,000	732,450	211,751	600,000	202,132	575,000
Manganiferous silver ores	60,000	600,000	60,000	600,000	60,000	600,000
Total	347,193	$1,610,086	306,275	$1,533,844	291,330	$1,454,416

The production in the above table is given in long tons.

EXPORTS OF MANGANESE ORES FROM THE UNITED STATES.

Twenty years ago, a considerable portion of the manganese production of the United States was shipped to England, but in later years the home consumption has steadily increased, and the exports have correspondingly decreased, until in 1888, the records of imports into Great Britain, France, Belgium, and Germany, as given in the Mineral Resources of the United States, for 1888, show no mention of shipments from America.

* Compiled from statistics in the Mineral Resources of the United States for 1886, 1887 and 1888.

Value of exports of manganese ores from the United States in certain years between 1869—1884.*

Fiscal Year Ending June 30.	Value.	Fiscal Year Ending June 30.	Value.
1869	$13,382 00	1875	$2,261 00
1870	56,125 00	1876	1,030 00
1871	7,760 00	1878	3,569 00
1873	41,075 00	1883	6,165 00
1874	9,939 00	1884	1,802 00

IMPORTS OF MANGANESE ORES INTO THE UNITED STATES.

General statement.—The imports of most foreign manganese ores, especially of manganiferous iron ores, are often obscured among those of iron ores, so that accurate statistics are difficult to obtain. A general summary, however, may be given.

Until the last three or four years, the Canadian manganese ores and the Spanish manganiferous iron ores have represented most of the raw manganese materials imported into the United States, though large quantities of manufactured spiegeleisen and ferro-manganese have been imported ever since their use in steel was introduced in this country.† Lately, however, importations of manganese ores from Cuba, Chili and Russia, as well as certain quantities from Turkey and Greece, have commenced.

Imports from Canada.—The manganese production of Canada comes from the provinces of New Brunswick and Nova Scotia. It is almost all imported into the United States, where it is used largely in glass-making, in electric batteries, as a dryer in varnishes and in various other minor industries. Only small quantities are used for spiegeleisen and ferro-manganese, and even these amounts are the low grade ores. The high grade Canadian ore brings too high a price for other purposes to allow it to be applied to these uses. The production of Canadian manganese is given later in this chapter. In 1888 it was 1,182 tons.

* Mineral Resources of the United States, 1883-1884, p. 557.

† See Imports of spiegeleisen and ferro-manganese, on page 28.

Imports from Spain.—Spanish manganiferous iron ores were used in the manufacture of spiegeleisen as early as 1875 at the Cambria Iron Works, Johnstown Pa., and the Bethlehem Iron Works, Bethlehem, Pa. Large quantities of ore are at present imported from Spain which contain from 5 to 12 or 15 per cent of manganese, though some go over 20 per cent. Spanish ores from Mazzarron and Goruguel are considerably used for admixture with other ores.

Imports from Cuba.—The importations of manganese ore from Cuba began over two years ago. In 1888, according to the Mineral Resources of the United States for that year, 1,581 tons were imported. This was consumed by Carnegie Brothers and Company at their works in Bessemer, Pa. Since that time the imports from Cuba have increased very much, and the statistics for 1890 will show an importation of several times as much as in 1888.

Imports from Chili.—Until lately most of the Chilian manganese ore has been exported to England, but during the past year or so imports into the United States have commenced. In the last few months Carnegie Brothers and Company have received considerable quantities from Chili.

Imports from Russia.—The Russian ore also, until lately, has gone largely to England, but is now being imported into the United States as well. Some 6,000 tons of Russian manganese ore were imported in the latter half of 1890.

PRODUCTION OF MANGANESE ORES, IN AND EXPORTS FROM CANADA, 1861-1888.

The provinces of New Brunswick and Nova Scotia, as already stated, produce practically all the manganese mined in Canada. The total production, from the time work was first commenced in 1861 to the present year (1890), has probably been less than fifty thousand tons. In former times, a large part of it was sent to England; now most of it is consumed in the United States. Only very little manganese is consumed in Canada and therefore the tables of exports represent very closely those of production.

Exports of manganese ores from Canada, 1868-73.*

FISCAL YEAR.	Nova Scotia.		New Brunswick.		TOTAL.	
	Tons.	Value.	Tons.	Value.	Tons.	Value.
1868	156	$4,700 00	861	$19,019 00	1,017	$23,719 00
1869	156	4,695 00	332	6,174 00	488	10,869 00
1870	1,256	4,102 00	146	3,580 00	1,402	7,682 00
1871	102	1,608 00	954	8,180 00	1,056	9,788 00
1872	131	4,005 00	1,075	24,495 00	1,206	28,500 00
1873	.....	.....	838	17,171 00	838	17,171 00
Total	1,801	$19,110 00	4,206	$78,619 00	6,007	$97,729 00

Exports of manganese ores from Canada, 1873-86.*

YEAR.	NOVA SCOTIA.		NEW BRUNSWICK.		TOTAL.	
	Tons.	Value.	Tons.	Value.	Tons.	Value.
1873	.....	.....	1,031	$20,192 00	1,031	$20,192 00
1874	6	$12 00	776	16,961 00	782	16 973 00
1875	.....	200 00	194	5,314 00	203	5,514 00
1876	21	723 00	391	7,316 00	412	8,039 00
1877 (a)	106	3,699 00	785	12,210 00	891	15,909 00
1878	106	4,889 00	520	5,971 00	626	10,860 00
1879	154	7,420 00	1,732	20,016 00	1,886	27,436 00
1880	79	3,090 00	2,100	31,707 00	2,179	34,797 00
1881	200	18 022 00	1,504	22,532 00	1,704	40,554 00
1882	123	11,520 00	771	14,227 00	894	25,747 00
1883	313	8,635 00	1,013	16,708 00	1,326	25,343 00
1884	134	11,054 00	469	9.035 00	603	20,089 00
1885	77	5,054 00	1,607	29,595 00	1,684	34,649 00
1886	(b) 441	30,854 00	1,377	27,484 00	(b) 1,818	58,338 00
Total	1,769	$105,172 00	14,270	$239,268 00	16,039	$344,440 00

* Eugene Coste, Statistical Report on the Production, Value, Exports and Imports of Minerals in Canada during the Year 1886 and Previous Years, p. 47; Geological and Natural History Survey of Canada, Alfred R. C. Selwyn, Director, 1887.

(a) 2 tons, valued at $6, were exported from Quebec that year.

(b) 250 tons from Cornwallis included in this quantity more properly come under the heading of mineral pigments.

Production of manganese ores in Canada, 1887–1888. *

YEAR.	NOVA SCOTIA.	NEW BRUNSWICK.	TOTAL.
	Tons.	Tons.	Tons.
1887	691	939½	1,630½
1888	88	1,094	1,182
Total	779	2,033½	2,812½

In 1890 the total maganese production of Canada was 1,455 tons, valued at $32,737.†

Production of manganese in Nova Scotia, 1872–1890.‡

YEAR.	TONS.	YEAR.	TONS.
1872	40	1881	231
1873	131	1882	205
1874		1883	150
1875	7	1884	302
1876	16	1885	353
1877	97	1886	427
1878	127	1887	691
1879	145	1888	88
1880	223	1889	67
		Total	3,300

The product for 1890 will probably not exceed that of 1889.

The production from the time Nova Scotia manganese was first worked in 1861 until 1871, inclusive, is quoted in the Mineral Resources of the United States for 1888, at 1,500 long tons.

* The statistics for Nova Scotia in this table have been kindly furnished the Survey by Mr. E. Gilpin, Jr., Commissioner of Mines for that province. Those for New Brunswick are taken from the Mineral Resources of the United States for 1888.

† Engineering and Mining Journal, January 3, 1891, p. 18

‡ These statistics have been kindly furnished the Survey by Mr. E. Gilpin, Jr., Commissioner of Mines for Nova Scotia.

*Imports of manganese ores into Canada.**

PROVINCE.	1885.		1886.	
	Pounds.	Value.	Pounds.	Value.
Ontario	20,158	$ 648 00	16,464	$ 824 00
Quebec	22,637	1,123 00	29,418	1,530 00
Nova Scotia	1,087	76 00	1,075	75 00
New Brunswick	950	27 00	.....	.....
Manitoba	.....	.....	609	26 00
Total	44,832	$ 1,874 00	47,561	$ 2,455 00

The production of manganese ores in the world in 1888.†

COUNTRY.	Long Tons.	COUNTRY.	Long Tons.
Caucasus (Russia)	48,653	Greece	385
United States	29,198	Italy, (1887)	1,652
Chili	24,746	Cuba	1,581
France, (1886)	7,676	Nova Scotia	106
Sweden	6,089	New Brunswick	1,094
Portugal	5,638	Quebec	3
Spain	2,830	Great Britain, (1887)	13,054
Australia	1,572	Bosnia	4,000
New Zealand	787	Holland	1,107
Turkey	669	Other countries	3,114
		Total	153,954

From the above table it will be seen that the United States is next to the largest producer of manganese ore in the world, being second only to the Caucasus region of Russia. It will also be seen that the Caucasus, the United States and Chili produce by far the larger part of the world's output. Their combined production in 1888 was 102,597 tons, which lacks only thirty-nine tons of being two thirds of the total production of the twenty or more countries represented as manganese producers in 1888.

*Taken from the statistical report of Eugene Coste, quoted above.

†Mineral resources of the United States, 1888, p. 143.

Imports of manganese ores into Great Britain, France, Belgium and Germany, 1888. *

IMPORTED INTO.	Long Tons.	IMPORTED FROM.	Long Tons.
Great Britain	74,906	Caucasus, (Russia)	48,653
France	6,174	Chili	24,746
Belgium	1,945	Spain	2,830
Germany	9,624	Portugal	5,638
		Turkey	669
		Italy	385
		Greece	500
		Sweden	6,089
		Australia	1,572
		New Zealand	787
		Canada	248
		Other countries	532
Total	92,649	Total	92,649

By comparing this table with the preceding one it will be seen that England is the largest consumer of manganese in the world, using not only its own production, but also 74,906 tons from outside sources; that the United States is not only the second producer, but the second largest consumer, using its own production as well as that of Cuba and most of that of Canada.

* Mineral Resources of the United States, 1888, p. 143.

CHAPTER V.

THE ORES OF MANGANESE.

MINERALOGICAL FORMS OF MANGANESE.

The metal manganese occurs in nature in a great number of different mineralogical forms, but the only ones that are, according to present standards, applicable to any considerable extent in the arts, are the oxides and the carbonates. The latter, though of frequent occurrence in small amounts, are so rarely found in large quantities in America, that the oxides represent practically all the ores of manganese now used in this country. Besides these, however, numerous other manganese-bearing minerals are found which, either on account of their chemical composition, or their limited quantity, are not available as sources of manganese. In some special cases, where such minerals are worked as a source of other metals, their residue has been profitably used for its contents of manganese. This is the case with the zinc ores of northern New Jersey, which contain a considerable percentage of manganese, and, after the extraction of the zinc, the residue is used in the manufacture of spiegeleisen.

The most common of the manganese-bearing minerals, with the exception of the oxides and the carbonates, contain manganese in the form of silicates, and are not used as a source of the metal, on account of their high percentage of silica. In some of these compounds, manganese is the only metal, but in most of them it is associated with greater or less quantities of iron and other substances. The simple silicate of manganese, known as *rhodonite* (see page 85), is the most abundant of this class of minerals, and is a common constituent of crystalline rocks. Among the others, containing manganese in greater or less quantities, may be mentioned the

several manganiferous minerals of the olivine group, such as *roepperite, tephroite, friedelite, knebelite, danalite,* and *helvite;* the manganiferous forms of *augite, hornblende* and *garnet;* the manganiferous form of magnesian mica known as *manganophyllite;* the manganiferous epidote known as *piedmontite;* the manganiferous form of *staurolite,* and the manganiferous minerals in the chlorite group, such as *prochlorite* and others; the manganiferous pectolite known as *manganopectolite,* from Magnet Cove, Arkansas, lately described by Dr. J. Francis Williams*; the alumina-iron-manganese-lime silicate known as *ilvaite* or *lievrite* and the related mineral known as *ardennite;* the beryllium-manganese-lime silicate, known as *trimerite,* found in Wärmland, Sweden and lately described by Gust. Flink.†

Among minerals containing manganese in other forms than as oxides, carbonates or silicates, may be mentioned the monosulphide of manganese, *alabandite* or *manganblende,* found in some of the silver veins in the Rocky Mountains, in the gold mines of Nagyag, Transylvania, and elsewhere; the disulphide, *hauerite,* from Kalinka, Hungary; the sulphates, *fauserite apjohnite* and *boæjemanite;* the arsenide, *kaneite,* found in Saxony; the arsenate, *chondrarsenite;* the compounds of manganese, iron and other metals with phosphorus in the form of *triphylite, lithiophylite* and *hureaulite,* or with phosphorus and flourine in the form of *triplite* and various related minerals; the compounds of manganese and iron with tungsten in the form of *wolframite,* and the compound of manganese alone with tungsten in the form of *huebnerite;* the magnesia-manganese borate, known as *pinaciolite,* from Wärmland, Sweden, lately described by Gust. Flink.‡ Numerous other instances of manganese-bearing minerals might be cited,|| but those given are sufficient to show the great variety of forms under which the metal occurs, and though many of them are of absolutely no value as sources of manganese,

* Zeitschrift f. Krystallographie und Mineralogie, P. Groth, Leipzig, Nov., 1890, pp. 386-389.

† Ibid. pp. 365-376.

‡ Ibid. pp. 361-365.

|| Others are mentioned farther on in this chapter.

some of them have played an important part, in the origin of the useful deposits of that metal. (See final chapter).

THE OXIDES OF MANGANESE.

General statement.—The most stable condition of manganese in nature is in the form of oxides, and, therefore, when any of the other manganese minerals are decomposed by the influences of surface agencies, they all tend, sooner or later, to go into that form. As a direct result of this, the oxides are the most plentiful of the manganese minerals. They occur in several different forms, varying considerably in the relative proportions of manganese and oxygen, that is, in the degree of oxidation of the manganese, and in the nature of the accompanying chemically or mechanically combined impurities. The most important, as regards quantity and usefulness in the arts, are, *pyrolusite, psilomelane, braunite* and *manganite;* less important are *hausmannite* and *wad.* Other oxides are *polianite* (see pyrolusite), *pyrochroite, chalcophanite* and the deep-sea nodules known as *pelagite.*

The minerals will be treated in the order named, except in the case of the somewhat rare polianite, which, on account of its relation to pyrolusite, is described with that mineral.

Pyrolusite or black oxide of manganese, peroxide of manganese.—Pyrolusite is a heavy, highly crystalline, iron-black mineral, very soft, and often easily crushed in the fingers, causing a deep black stain. It has a hardness of 2 to 2.5, a specific gravity of 4.8, and a black streak. It belongs to the orthorhombic system of crystallization and occurs in more or less modified rectangular prisms. Sometimes the crystals are an inch or more in length, fibrous and needle-shaped, standing up at right angles to the base on which they rest, but more generally they are in clusters, radiating more or less regularly from a center; at others, they are closely compacted into a solid body, and often they are small and compose a brightly glittering, granular mass. The most beautifully crystallized pyrolusite found in America is that from the Tenny Cape mine, in Nova Scotia, though well developed forms are also found in Virginia, Georgia and southwestern Arkansas.

In chemical composition, pyrolusite is a peroxide of manganese, having the formula MnO_2, and containing 63.2 per cent of manganese and 36.8 per cent of oxygen, though it is never found in nature in this degree of purity. Peroxide of manganese can readily be made to give up a part of its oxygen, and on this property, as has been explained more fully in chapter III., depends its value in the manufacture of chlorine. Its value for the manufacture of spiegeleisen and ferro-manganese depends on its metallic contents. The name pyrolusite is derived from the Greek *pur*, fire, and *luo*, to wash, and refers to the use of the mineral in freeing glass from the green color given to it by iron. The name was given by Haidinger in 1827.*

Pyrolusite is supposed in many cases to be a product of the alteration of manganite, as is mentioned further under the description of that mineral. The mineral *varvacite* is an impure pyrolusite.

Polianite.—The mineral polianite has the same composition as a very pure pyrolusite, consisting of almost absolutely pure peroxide of manganese. It was first described and named by Breithaupt† in 1844, but its independent position was established beyond all doubt by Professors Edward S. Dana and Samuel L. Penfield in 1888.‡ It is distinguished from pyrolusite by its very much greater hardness, which, according to the experiments of Dana and Penfield, is 6 to 6.5, and by its white or light steel gray color. It has a specific gravity of 4.992 (Dana and Penfield), which is a little greater than that of pyrolusite (4.8), and it belongs to the tetragonal system of crystallization. It is considered to be an alteration product of manganite, and crystals of polianite have been found in the hollow interiors of altered manganite prisms.

Polianite occurs in too small quantities to be of any commercial value as a manganese ore.

Psilomelane.—This is a heavy, black, steel-blue or, more rarely, greenish-black mineral, very hard, and occurring in a

* Trans. Roy. Soc. Edinburgh, Vol. XI., 1827, p. 119.

† Pogg. Ann. Vol. LXI, 1844, p. 191.

‡ Amer. Jour. Sci., Vol. CXXXV., 1888, pp. 243-247.

massive form. It has a hardness of 5 to 6, a specific gravity of 4 to 4.4, and often shows a well developed conchoidal fracture. It is very much harder than pyrolusite, but can usually be faintly scratched with a knife. It commonly occurs in botryoidal, mammillary or kidney-shaped masses, and the name psilomelane refers to their smooth surfaces, being derived from the Greek words *psilos*, smooth, and *melas*, black. The ore on a fresh fracture, often shows a bright steel-blue, glossy lustre.

In chemical composition, psilomelane is largely a peroxide of manganese with variable amounts of water, potash and baryta. The water is sometimes absent altogether, and at others, is present to the extent of over six per cent. The potash is equally variable, and sometimes composes over four per cent of the mineral. The baryta, though occasionally absent, is generally found in greater or less quantities, varying from 0.10 per cent to over 17 per cent of the mass. By some mineralogists, the potash and baryta are supposed to be mechanical admixtures, and by others they are considered to be in chemical combination, forming the base of a compound in which a part of the peroxide of manganese acts as the acid. It is very difficult to determine under what conditions they are present, as psilomelane occurs in the massive form, and therefore it is always doubtful whether any specimen is a perfectly pure sample of the mineral. The contents of manganese vary according to the percentages of other ingredients, and range, when the ore is pure, from forty-five to sixty per cent.

Psilomelane is one of the most abundant of the manganese ores found in nature, and it occurs to a greater or less extent almost everywhere that pyrolusite is found. The mode of occurrence of psilomelane and pyrolusite in nature leads to the belief that, in some cases at least, the two minerals are closely related. Both frequently form part of the same mass, blending into each other without any sharp line of separation, and it is common to have an incrustation of crystals of pyrolusite radiating from a kernel of psilomelane, or else similar crystals lining the interior of a geode of psilomelane. Such associations are frequently seen in parts of Nova Scotia and elsewhere.

Frequently nests of solitary crystals of pyrolusite are scattered through the pislomelane, and, in fact, wherever the two minerals occur together, they are generally associated in such a manner as to suggest the possible derivation, by chemical alteration, of the pyrolusite from the psilomelane. Another fact leading to the same supposition, is that, in the case of a bedded deposit, it often happens that the greater the amount of chemical action which has gone on, the greater is the proportion of pyrolusite as compared with psilomelane. Such evidence as these facts afford, however, is of but little value without the further evidence of mineralogical investigation.

Braunite.—This is a heavy, black, or brownish-black mineral, very hard, occurring in both the massive and crystalline forms, with a dark brown streak and a submetallic lustre. It has a specific gravity of 4.8, and a hardness of 6-6.5, being often too hard to be scratched with a knife. When crystallized, it belongs to the tetragonal system, and frequently occurs in the form of pyramids.

In chemical composition, braunite is an anhydrous oxide, generally containing silica, sometimes to the extent of over 8 per cent. Professor J. D. Dana, in his System of Mineralogy, fifth edition, thinks that the silica is in chemical combination with the oxide of manganese.

Braunite is also considered by some mineralogists to be sometimes simply an anhydrous sesquioxide of manganese, having the formula Mn_2O_3 and containing silica as a mechanical admixture. In some cases, however, the silica when present, is undoubtedly in chemical combination with the manganese. This has been clearly proved by the late investigation of pure crystals of braunite, by Dr. S. L. Penfield. Silica, however, is not invariably present in braunite, and samples have been analyzed which were almost entirely free from it.* When pure, braunite contains an average of sixty-nine per cent of metallic manganese, but it is never found in this degree of purity in nature.

Manganite.—This is a heavy, black mineral, softer than

* For a further discussion of braunite see the description of the manganese ores of the Batesville region, Arkansas, in chapter VII.

braunite, but harder than pyrolusite, sometimes massive, sometimes crystalline, and has a brown or black streak. Its specific gravity is 4 3 to 4.4, and its hardness is 4 to 4.5. It is easily scratched with a knife. It belongs to the orthorhombic system of crystallization, and frequently occurs in strongly striated prisms. It is found at Tenny Cape; Cheverie, Walton, and other places in Nova Scotia, and at Markhamville, and elsewhere in New Brunswick. It is frequently associated with pyrolusite and psilomelane. It probably, also, occurs among some of the ores of Virginia, Georgia and Arkansas.

In chemical composition, manganite is a hydrous sesquioxide of manganese, having the formula $Mn_2O_3.H_2O$ and containing 62.5 per cent of manganese, 27.3 per cent of oxygen, and 10.2 per cent of water. When the water is removed from manganite, it changes to pyrolusite, hausmannite or braunite, and in some cases these minerals, as found in nature, have been supposed to be altered manganite. This is especially true of pyrolusite, which, in many cases, is a pseudomorph after manganite. Crystallized specimens have been found in which the crystals at one end had the composition of manganite, while those at the other, though of the same form, were composed of pyrolusite. Consequently, there can be no doubt that pyrolusite, in some cases, has been derived from manganite, but whether it is always derived from it is, as yet, in doubt.

Hausmannite.—This is a heavy, brownish-black mineral, massive or crystalline, harder than manganite, but softer than some forms of braunite. Its specific gravity is 4.7 and its hardness 5 to 5.5. It can be faintly scratched with a knife. It belongs to the tetragonal system of crystallization, and is sometimes found in the form of pyramids. It is rare.

In chemical composition, hausmannite has the formula, according to Dana, * of $2MnO.MnO_2$. When pure it contains 72.1 per cent of manganese, 29.9 per cent of oxygen, though it is never found in nature in this state of purity. A zinc-bearing hausmannite, known as *hetearolite*, occurs at Sterling Hill, N. J.

* System of Mineralogy, fifth edition, p. 162.

Wad, or bog manganese.—This is a low grade, light, earthy, brown or black ore, varying from a soft, loose, porous mass to a very hard variety, which can hardly be scratched with a knife. The soft variety, however, is the most common form. It is never crystalline. Its hardness is from 1 to 6, and its specific gravity from 3 to 4.

The chemical composition of wad is very variable. It is essentially an impure peroxide of manganese, containing from fifteen to forty-five per cent of the metal, mechanically mixed with different quantities of other ingredients. It contains a greater or less amount of sesquioxide of iron, and, in fact, is often mixed with so much of that material that it blends into a bog iron ore. It contains a very variable and often a very large quantity of water, from less than ten per cent to over twenty-five per cent. It frequently contains cobalt, and sometimes nickel. The mineral *asbolite* is a wad with large quantities of oxide of cobalt, sometimes running up to as much as thirty-two per cent. The common wad, however, contains much less. A sample from Long Gully, near Bungonia, New South Wales, was found by Dr. Thomson* to contain 1.57 per cent of cobalt, and 0.36 per cent of nickel. A considerable quantity of copper is often found in wad, and a variety containing from four to eighteen per cent is known as *lampadite* or *cupreous manganese*. *Reissacherite* is a form of wad containing a large percentage of water; and *groroilite* is another name for ordinary wad.

Wad sometimes occurs in irregular masses in clay, and sometimes as a solid bed, often several feet thick. It is found in connection with rocks of almost all geologic ages, but is usually a secondary product, and does not always represent a material laid down in its present form at the time of the deposition of these rocks. This is especially true with the older formations and noticeably so with crystalline rocks, where wad often occupies hollows and basins in their surfaces and has come from the disintegrating of either some of the other oxide ores already described, or, more generally, of the various silicates of manganese, and occasionally of the carbonate.

* Ure's Dict. Arts, Manufactures and Mines, Vol. IV., Supplement, 1878.

Wad is too low grade and contains too many injurious impurities to be used as a source of manganese, or to be employed in the manufacture of chlorine. It is occasionally used as the basis of a black or brown paint, and in some places there is a considerable local consumption of it for this purpose.

The black arborescent figures, known as *dendrites*, frequently seen lining the sides of cracks, joints and faults, are often, or even generally, manganese in the form of wad or some other oxide. Some of them, however, especially the brown dendrites, are formed of iron oxides. They have all been deposited from waters carrying manganese or iron, or both, in solution, and percolating through the crevices of the rock. The figures in moss-agates are due to the same substances occupying a moss-like form instead of the branching form observable elsewhere.

Pyrochroite.—This is a white mineral having the composition of a hydrous protoxide of manganese and the formula MnO_2H_2. It is very rare and is not found in quantities sufficient to be of any commercial importance. It occurs at Sterling Hill and Franklin, New Jersey, and in Sweden.

Chalcophanite.—This is a hydrous oxide of manganese and zinc, of a bluish- or iron-black color and a chocolate-brown streak. It occurs in rhombohedral crystals, and in stalactitic and plumose masses. It is about as hard as some varieties of pyrolusite, being rated at 2.5. It is supposed to be the product of decomposition of the mineral *franklinite*, and is found in the zinc deposits of Sterling Hill, New Jersey.

Pelagite.—This is the name given to the manganese nodules found in the deep-sea dredgings. They consist of a mixture, probably a mechanical one, of peroxide of manganese and sesquioxide of iron, with silica, alumina and water. The percentage composition is approximately as follows:

Peroxide of manganese.....	40.00 per cent.
Sesquioxide of iron.....	27.00 " "
Silica.....	14.00 " "
Alumina.....	4.00 " "
Water (at red heat).....	13.00 " "

(Water below 100° C. 24.5 per cent.)

CARBONATES OF MANGANESE.

Rhodochrosite.—The simple carbonate of manganese is known as *rhodochrosite* or *diallogite*. Its characteristic color, when freshly broken, is pink or light rose-red, and hence the name *rodochrosite*, from the Greek adjective, *rodochroos*, meaning rose-colored. This color, however, fades on exposure to the air and becomes white or buff, and in cases even darker, as a result of the partial oxidation of the mineral. It is easily scratched with a knife, having a hardness of 3.5 to 4.5. It has a specific gravity of 3.4 to 3.7. It crystallizes in the hexagonal system, and is often found in beautiful pink rhombohedrons.

It contains, when theoretically pure, 38.6 per cent of carbonic acid, and 61.4 per cent of protoxide of manganese, which is equal to 47.56 per cent of metallic manganese. It is never, however, found in nature in this degree of purity.

This ore is very generally distributed, but is usually in small quantities, and is not mined as a source of manganese anywhere in America. It is found in many of the silver veins in the Rocky Mountains. At Butte City, Montana, when the water level of the country is reached, a mixture of carbonate and silicate of manganese often forms a large part of the gangue material. Above the water level, the manganese is in the form of oxides. In the San Juan Mountains, in southwestern Colorado, beautiful crystals of rhodochrosite are frequently found. Dr. T. S. Hunt describes carbonate of manganese in the dolomites of Eastern Canada, and as interbedded lenticular strata associated with silicate of manganese in the crystalline schists of New England. It is also described by Dr. Hunt in slates of probably Silurian age at Placentia Bay, Newfoundland.* It is a very common ingredient of limestones of all ages, though almost always in very small quantities. As will be shown under the discussion of the origin of manganese ores in the final chapter of this volume, the carbonate is probably the original form of many of the oxide ores now worked as a source of manganese.

Ankerite.—This is a carbonate of lime, magnesia and iron, frequently containing manganese.

* Amer. Jour. Sci., 1859, Vol. XXVIII., p. 374.

Manganocalcite.—This is a lime-manganese carbonate and much rarer than the simple carbonate of manganese.

SILICATES OF MANGANESE.

Rhodonite.—The simple silicate of manganese is known as *rhodonite* or *manganese spar.* Its characteristic color is flesh-red or pink, and hence the name *rhodonite,* from the Greek *rhodon,* a rose. Sometimes, however, when impure, it is yellow, brown, or even green. It is very often blackened on the outside by oxidation. It has a colorless streak, a vitreous lustre, a specific gravity 3.4 to 3.7 and is transparent to opaque. It is hard and often cannot be scratched with a knife. Its hardness is 5.5 to 6.5. It belongs to the triclinic system of crystallization, though it is usually found in the massive form.

In chemical composition, rhodonite has the formula, when pure, $MnSiO_3$, containing 45.9 per cent of silica, and 54.1 per cent of protoxide of manganese, equal to 41.90 per cent of metallic manganese.

On exposure to surface influences, rhodonite becomes oxidized and converted into one or more of the black oxides already described. Sometimes this alteration has penetrated the mass down to the water level of the country, where usually the pure silicate is found. Generally, however, the change is much more superficial, and the oxidation runs down into the deposit along joint cracks and fissures, only partially altering it and giving it the appearance of a pink or brown material, cut up by a net-work of intersecting straight or irregular black lines. From this the oxidation increases until the whole mass has a black color, studded here and there with lighter colored kernels of unaltered silicate, and, eventually, even these disappear.

Rhodonite is sometimes found in considerable quantities, but is not used as a source of manganese on account of its very large percentage of silica. It is sometimes used in the glaze on pottery, and to give a violet tint to glass. Also, the pure, finely colored varieties are used as ornamental stones, and are sometimes cut for gems. Its consumption, however, is small.

Rhodonite frequently occurs with the carbonate of manganese at the localities mentioned under that heading. It is a common mineral in metamorphic and igneous rocks, sometimes forming interbedded lenticular layers, and sometimes occurring in veins. In some of the silver veins of Butte City, Montana, and in Colorado and other places, it often forms a large proportion of the gangue material. It is also found in many parts of New England, at Plainfield and Cummington, Mass.; at Blue Hill, Maine, and elsewhere. It is a very frequent accompaniment of the crystalline rocks of Virginia, North Carolina and Georgia.

Bustamite.—This is a silicate of manganese containing 9 to 15 per cent of lime, which replaces part of the manganese. It often contains carbonate of lime, and, from the presence of this, it has been suggested that part of the lime replacing the manganese has resulted from partial alteration. *

Fowlerite.—This is a zinc-bearing rhodonite.

Tephroite.—This is a manganese olivine, having the formula Mn_2SiO_4. It occurs at Sterling Hill, New Jersey. Other silicates have already been mentioned on page 76.

CLASSIFICATION OF ORES CONTAINING MANGANESE.

Intimate association of oxides of manganese.—As already stated, the oxides are the only ores of manganese in this country, so far as yet known, which are commercially important as a source of the metal. These are rarely found singly, being almost always associated with greater or less quantities of each other. The one variety blends into the other, and it is often impossible to draw any sharp line of separation between them. So intimate a mixture is often found, that it is difficult to decide, without a very careful analysis, to which variety a certain ore should be assigned. It only too often occurs that in mentioning manganese ores, the names of the various oxides are most indiscriminately applied without any evidence at all that the appellation is properly used. The most marked difference in the general appearance of the ores is their crystalline or massive character. Pyrolusite is always crystalline, and psilomelane is massive,

* J. D. Dana, System of Mineralogy, fifth edition, p. 225.

while braunite and manganite are sometimes crystalline and sometimes massive. Therefore, in the descriptions of different localities given in future chapters, wherever detailed analyses are not obtainable and there is any doubt concerning the exact mineralogical composition of an ore, it is referred to simply as *crystalline* or *massive*, as the case may be, the former including pyrolusite and the crystalline forms of braunite and manganite, or even admixtures of two or more of the three forms; the latter including psilomelane and the massive forms of braunite and manganite, or admixtures of two or more of them.

Manganese with iron, silver and zinc.—Not only are the oxides of manganese mixed with each other, but they are often associated with a greater or less quantity of oxide of iron, forming a ferruginous manganese ore; or, when the iron predominates, a manganiferous iron ore. Sometimes manganese ores contain considerable quantities of silver, and are more valuable for their contents of that metal than for their manganese contents. In some places also, as in northern New Jersey, manganiferous zinc ores occur, which are valuable for both their zinc and manganese. These varieties of manganiferous ores have become so important in the United States, that it is necessary to divide manganese bearing ores into four classes, differing considerably in their ingredients and in the uses to which they are applied. They are, *manganese ores proper, manganiferous iron ores, manganiferous silver ores* and *manganiferous zinc ores.*

MAGANESE ORES PROPER.

These have already been described, and do not require further mention. As already stated, they consist of various oxides of the metal more or less intimately mixed, and, in some rare cases, are represented by carbonates.

MANGANIFEROUS IRON ORES.

Generally, manganese ores are more or less mixed with iron and frequently the latter increases in quantity until it forms the predominating feature of the ore, at times almost totally replacing the manganese. Between the two extremes of a manganese ore with a little iron and an iron ore with a little manganese,

there are all stages of admixture of the two materials. The iron in manganiferous iron ore may be in almost any of the common forms of iron ores, such as brown hematite and other forms of limonite, red hematite, specular ore, magnetic ore, and spathic ore.

Sometimes the iron and manganese are intimately mixed, so that they have the appearance of a homogeneous mass, resembling an iron ore when the iron is in the preponderance, and a manganese ore when manganese predominates. In such cases there appears to be no tendency to combine in any one fixed proportion. When it is considered, however, that both the iron and the manganese in many deposits of manganiferous iron ore, especially in manganiferous brown hematites, were, probably, originally in the form of carbonates, and that carbonate of iron and of manganese, being isomorphous substances, can replace each other in all proportions, the variable quantities of the two metals in the oxide ores that have been derived from the carbonates is not extraordinary. At other times, the manganese occurs as nests of crystals in hematite, or as nodules of massive, hard ore, and also as inclusions of a dull black or brown earthy wad, the latter being well seen in some of the brown hematite of the Londonderry mines, Nova Scotia. In Virginia, very common occurrences are interstratified layers of hematite and manganese, either blending into each other or separated by a sharp line of demarcation. In such cases, the iron ore is always in the larger quantities and the more continuous deposits; while the manganese is often represented by thin lenticular beds, disconnected pockets or irregularly disseminated nodules. In southwestern Arkansas, a stalactitic ore is found in which the interiors of the stalactites are hematite, and the exteriors are massive manganese ore; also, geodes, with an outside incrustation of brown hematite and an inside layer of manganese ore, are found in parts of the same region. Such occurrences may be due to the different character of the metalliferous solution which affected the rocks at different times; but, as is shown under the discussion of the origin of manganese ores, it is possibly also due, in some cases, to the different methods of solution and redeposition of the two metals.

The principal regions where the manganiferous iron ores are found, are in the Lake Superior region of Michigan and Wisconsin, and in smaller quantities in Vermont, New Jersey, Pennsylvania, Virginia, Tennessee, North Carolina, Georgia, Alabama and many other places. Extensive deposits have lately been discovered in Gunnison County, Colorado. The Lake Superior region, however is the principal source of this ore at present, especially the Colby mine, in the Gogebic range, Michigan. This mine produces nearly all that is mined in the United States. Statistics of production have already been given on page 67. The ore is a red hematite containing from one to thirty three per cent of metallic manganese. The latter amount is, however, rare in this region, and the usual quantity varies from two to four per cent, though 11,562 tons of the 1888 product contained eleven per cent. The manganiferous iron ores of the Appalachian Mountains are usually brown hematite, though sometimes red hematite and magnetic varieties also occur.

No sharp line of division can be drawn between manganese ores proper and manganiferous iron ores. The one class blends into the other, and any division must be arbitrary. The use of such ores for the manufacture of spiegeleisen and ferro-manganese is not a case, such as the chemical uses of manganese, where an ore, containing under a certain percentage of the desired ingredient, is unmarketable. On the contrary, all the manganiferous iron ores, free from deleterious ingredients find a ready market, the higher grade for the manufacture of spiegeleisen and ferro-manganese, and the lower grade for the manufacture of low-manganese pig or of ordinary pig iron. The manganiferous iron ores low in manganese are sold simply as iron ores, and the manganese in them is either paid for at the same rate as iron or, when under certain percentages, is not paid for at all.

It has not been within the scope of time and means available for this report, to make a thorough investigation of manganiferous iron ores in the various regions of the United States, but several localities that have been visited are described with the manganese ores of various states.

MANGANIFEROUS SILVER ORES.

Manganiferous silver ores are a characteristic feature of many of the metalliferous veins of the Rocky Mountains, especially of Butte City, Montana; Leadville, Colorado; and Tombstone, Arizona. Above the water level of the country, the manganese usually occurs in the form of one or more of the oxides already described; below the water level, the oxides very often, especially at Butte City, pass into the carbonate (rhodochrosite) and the silicate (rhodonite). The last two minerals doubtless represent the original condition of the oxides, which have, by the action of surface influences, assumed their present oxidized condition.

The various forms of manganese, in manganiferous silver ores, are associated in different places, with different gangues: sometimes with a highly siliceous gangue of almost pure quartz, or with a highly calcareous one; sometimes with an iron ore, forming a manganiferous iron ore gangue; and at still others the manganese minerals themselves comprise the larger part of the gangue. At Butte City, manganese sometimes forms over fifty per cent of the gangue, and from this it decreases to less than twenty per cent. At Leadville, the manganese and iron often form almost the whole gangue, and the analysis of seventeen samples of this used at the Colorado Coal and Iron Company's works as a source of speigeleisen, show 9.3 to over 51 per cent of manganese, and from 1.33 to over 48 per cent of iron. At Tombstone, the manganiferous ores contain from ten to over thirty per cent of manganese.

In these manganiferous gangue materials, the silver occurs in many different forms, and in quantities varying from so small that it hardly pays to work them, up to many dollars per ton in value. Sometimes it occurs as chloride, and at other times as metallic silver or as argentiferous zinc blende, and also in other forms. These ores also frequently contain limited quantities of gold, lead, copper, antimony and other metals.

Very few of such manganiferous ores are used as a source of manganese, since their silver contents are more valuable than

their manganiferous contents, and, as they cannot be used as a source of both materials, they are, of course, devoted to the most profitable purpose. In fact, even if they were not of value as a source of silver it is probably in very few cases that they are in sufficient quantities and of such quality as to be useful as a source of manganese. Leadville and a few other places in Colorado are exceptions to this, and there the manganiferous gangue is separated from the silver ores and shipped for the manufacture of speigeleisen. But, though elsewhere the ore is not used for such purposes, the manganese oxides in it are of value in smelting the ore for its silver, as they play the part of iron as a fluxing material. The manganese is paid for at the rate of ten cents per unit, the same price as is paid for iron, and the ores containing it are valued for admixture with other more refractory ores.

The Rocky Mountains are the principal region of manganiferous silver ores in the United States, but these ores are also found in Nevada and elsewhere. In fact, silver in very small quantities is a very common constituent of many of the manganese oxides, not only in vein deposits, but also in bedded ores. Thus, a sample of manganese ore from Tenney Cape, Nova Scotia, is said by Professor H. How * to have assayed five dollars per ton in silver; the bedded manganese deposit near Golconda, Nevada, is said to afford three dollars per ton in silver, and the ore of the Spiller manganese mine in Mason county, Texas, was once worked as a source of the same metal.

MANGANIFEROUS ZINC ORES.

Manganese is a common accompaniment of the zinc ores of Sterling Hill and Franklin, Sussex county, New Jersey. The zinc minerals are mostly franklinite, an iron-manganese-zinc oxide; zincite, a zinc oxide generally containing more or less manganese; and willemite, a silicate of zinc. These minerals are associated with each other in varying proportions, and occur with calcite in a white crystalline limestone. In the same region are found other manganese-bearing minerals in smaller quantities,

* London, Edinburgh and Dublin Phil. Mag., March 1866.

such as fowlerite, a zinciferous silicate of manganese; tephroite, a silicate of manganese; roepperite, an iron-manganese-zinc silicate; and chalcophanite (Sterling Hill), a hydrous oxide of manganese and zinc.

The ores are mined, primarily, as a source of zinc, but, after the extraction of that metal, the residuum, known as "clinker", is used in the manufacture of spiegeleisen. The crude ore is heated in a furnace and the zinc is volatilized and collected in the form of oxide. The percentage of manganese in the residuum is increased over that in the ore by the removal of the zinc and frequently amounts to 12 to 16 per cent.

The composition of the ore and of the residuum are given in the first two tables below. The ores as mined, however, are mixtures in varying proportions of the minerals mentioned above, mostly franklinite, zincite and willemite with calcite, and therefore do not represent the composition of any one mineral. Analyses which do show such compositions are, therefore, also given.

*Analyses of manganiferous zinc ores of New Jersey.**

Manganese protoxide (MnO)	15.84	16.46	17.63	15.66	15.95	12.30	12.21	13.09	17.81
Iron sesquioxide (Fe_2O_3)	31.41	31.63	27.54	30.46	30.36	30.33	30.13	27.62	27.20
Alumina (Al_2O_3)	.21	.80	.24	.09	1.16	.67	.....	.64	.67
Zinc oxide (ZnO)	32.83	34.07	35.88	27.15	26.34	29.42	27.12	23.38	22.94
Lime (CaO)	5.09	4.08	2.01	8.45	7.15	12.65	12.63	14.37	11.46
Magnesia (MgO)	.....	.21	.77	.91	1.09	.....	1.69	1.98	.74
Silica (SiO_2)	10.21	9.91	11.08	10.28	10.33	4.86	4 43	5.15	9.78
Metallic manganese	12.27	12.75	13.60	12.12	12.35	9.53	9.46	11.13	13 79
Metallic iron	21.98	22.14	19.28	21.32	21.25	21.23	21.09	19.33	19.04
Metallic zinc	26.34	27.34	28.78	21.79	21.14	23.61	21.76	18.76	18.41

* Quoted in Mineral Resources of the United States, 1885, p. 837, from Geo. S. Stone, Engineer New Jersey Zinc Company.

*Analyses of "clinker" from manganiferous zinc ores of New Jersey.**

Manganese protoxide (MnO)	17.83	16.22	15.66	18.90	21.03
Iron sesquioxide (Fe_2O_3)	33.21	31.06	33.84	36.16	31.06
Alumina (Al_2O_3)	2.25	6.36	8.24	6.94	5.98
Zinc oxide (ZnO)	10.74	6.98	4.98	4.06	7.84
Lime (CaO)	11.96	10.73	11.04	11.81	7.60
Magnesia (MgO)	2.30	2.67	1.84	1.98	4.01
Silica (SiO_2)	19.97	25.02	23.47	18.14	21.29
Phosphorus	.037				
Metallic manganese	13.82	12.56	12.13	14 64	16.29
Metallic iron	23.25	21.74	23.69	25.30	21.74
Metallic zinc	8.62	5.60	3.17	3.26	6.29

Analyses of franklinite, zincite, and willemite from New Jersey.

	FRANKLINITE.		ZINCITE.		WILLEMITE.	
	1.	2.	3.	4.	5.	6.
Manganese sesquioxide (Mn_2O_3)	11.99	18.17	12.00	3.70	2.66	
Manganese protoxide (MnO)						9.22
Iron sesquioxide (Fe_2O_3)	66.11	68.88			0.67	
Iron protoxide (FeO)						trace.
Alumina (Al_2O_3)		0.73				
Zinc oxide (ZnO)	21.77	10.81	88.00	96.19	71.33	60.07
Magnesia (MgO)						2.91
Water (H_2O)						1.00
Silica (SiO_2)	0.13	0.40			25.00	26 80
Total	100.00	98.99	100.00	99.89	99.66	100.00
Undecomposed residue				.10		
				99.99		
Metallic manganese	8.34	12.65	8.62(?)	2.58	1.85	7.14
Metallic iron	46.28	48.22			0.47	trace.
Metallic zinc	17.46	8.67	70.59	77.16	57.22	48.19

(1.) By G. J. Dickerson, in Rept. on New Jersey Zinc Mines by C. T. Jackson.
(2). By Abich, Pogg. Ann., Vol. XXIII., p. 342.
(3). By Berthier, Annales des mines, Vol. IV., p. 483.
(4). By Whitney, Pogg. Ann., Vol. LXXI., p. 169.
(5). By Vanuxem and Keating, Jour. Acad. Nat. Sci. Phila., Vol. IV., 1824, p. 8.
(6). By Hermann, Jour. Prakt. Chemie, Vol. XLVII., p. 11.

* Quoted in the Mineral Resources of the United States, 1885, p. 338, from Geo. S. Stone, Engineer New Jersey Zinc Company.

MANGANESE WITH COBALT AND NICKEL.

One of the most noticeable features of manganese oxides is the very frequent presence in them of small quantities of cobalt. This sometimes exists only as a trace, and from that increases up to several per cent, but, though in small quantities, it is remarkably persistent in its presence. It is especially characteristic of wad, and often occurs in it in larger quantities than in the other ores of manganese. (See wad, on page 82.) Wad is generally a subaerial deposit, existing near the source of supply of its metallic constituents, and this is especially true in regions of crystalline rocks. In such a deposit, the mineral constituents cannot have come from any great diversity of sources, and it seems likely that the cobalt had its origin in the same rocks as the manganese ores. Probably the cobalt in all manganese ores had a similar origin, and its excess in wad over other ores, may be due to the fact that the latter were generally deposited at a greater distance from their source than wad, and, therefore, there was a better opportunity for the separation of the two metals.

Nickel is also frequently found in a similar manner in manganese ores, but it is usually in smaller quantities than cobalt, and is not so constant a constituent as that metal.

MANGANESE WITH TUNGSTEN.

Manganese is sometimes associated with the metal tungsten. The association usually occurs in the form of wolframite, which is an iron and manganese tungstate; or of huebnerite, which is an exclusively manganese tungstate. The former is found in several places in New England, also in North Carolina and Missouri. The latter occurs in the Mammoth District, Nevada, * and in the Gagnon silver mine, Butte City, Montana. † An interesting occurrence of tungsten has also been found in samples of manganese ore collected by the writer in the Pleistocene shore

* Amer Jour. Sci., Vol. XLIII., 1867, pp. 123-4.

† Richard Pearce, The Association of Minerals in the Gagnon Vein, Butte City, Montana. Trans. Amer. Inst. Mng. Eng., XVI., 1877-8. p. 64.

deposit of the extinct Lake Lahontan, in Nevada, described by I. C. Russell.* The ore is an oxide of manganese, containing small quantities of iron, magnesia, baryta and other constituents. An analysis by R. N. Brackett, chemist of this Survey, showed the presence of 2.78 per cent of tungstic acid, which may, possibly, be in combination with the manganese, or with that and iron, in the form of one of the tungsten minerals already mentioned.

MANGANESE WITH BARIUM.

Barium is an ordinary accompaniment of manganese oxides. As already stated, it forms a characteristic constituent of psilomelane, but it also occurs in separate masses in the form of barite or sulphate of barium, with this ore as well as with the other manganese oxides. Such occurrences are seen at several places in Hants county, Nova Scotia; in northern Georgia; and elsewhere. At the Satterfield property, in Georgia, nodules of barite are found in the clay bed containing the manganese ore; and in the Nova Scotia area it is frequently found in crystals adhering to masses of ore.

MANGANESE WITH PHOSPHORUS.

Phosphorus is a very common constituent of manganese oxides, usually existing as only a fraction of a per cent, but sometimes running up to over 4 per cent. It forms the most injurious element in the manufacture of spiegeleisen or ferromanganese, as ores containing even two-tenths of one per cent of it are looked on with disfavor by manufacturers.

MANGANESE WITH THE RARER METALS.

Besides the materials already mentioned as being found with manganese ores, numerous rarer metals sometimes occur in small quantities, such as yttrium, thallium, indium, etc. In fact, though the number of large constituents of manganese

* Geological History of Lake Lahontan, a Pleistocene Lake of Northwestern Nevada. Monograph XI., U. S. Geological Survey, J. W. Powell, Director, 1885.

oxides are few, yet when the ores are examined in their minute details the number is very large and the composition of the ores very complicated. This is shown in a remarkable manner in the following two analyses, the first (1) by T. L. Phipson, * of a specimen from an unknown locality, the second (2) by Andrew S. McCreath, † of a specimen from the Crimora manganese mine, Virginia.‡

* Chemical News, June, 1876.

† Amer. Inst. Mng. Eng., Vol. XII., 1883-84, p. 22.

‡ These two analyses are intended to show the chemical nature of certain manganese oxides and not their commercial value in large shipments. Analyses for the latter purpose are given in the succeeding chapters, in the descriptions of the various manganese regions of the United States and Canada.

Analyses of manganese oxides.

	1.	2.
Manganese peroxide	72.17	81.708
Manganic oxide	6.20	.....
Manganese protoxide	.....	7.281
Ferric oxide	3.66	0.583
Alumina	0.90	0.896
Yttria	0.10	.....
Cobalt oxide	trace	0.354
Nickel oxide	0.04	0.996
Zinc oxide	.....	0.623
Lead oxide	0.14	.....
Thallium oxide	0.01	.....
Copper oxide	0.09	.....
Bismuth oxide	trace	.....
Arsenic oxide	0.15	.....
Indium oxide	distinct trace	.....
Lime	4.01	0.880
Baryta	0.58	0.829
Magnesia	0.24	0.630
Potash	0.70	alkalies 0.467
Lithia	trace	.....
Water	2.02	3.405
Carbonic acid	3.20	.....
Phosphoric acid	0.35	0.171
Silica	Silica and rock 4.00	2.132
Loss, including flourine	1.44	.....
Total	100.00	100.000

MANGANESE WITH NITROGEN.

M. M. Deville and Debray * have shown that pyrolusite or peroxide of manganese contains many soluble salts, and that the mineral, as it occurs in nature, has really a very complex constitution. By heating a sample of pyrolusite from Giessen, they obtained appreciable quantities of nitrogen in the oxygen that was evolved. Both Scheele and Berzelius had previously observed that nitrous vapors were given off in the process of obtaining oxygen from pyrolusite, but they had not investigated the matter, as did Deville and Debray. The latter, following up their observations on the vapor from the peroxide, digested a part of the mineral in distilled water and obtained a solution of sulphate of calcium, chlorides of sodium, calcium, and magnesium, and nitrates of sodium and potassium. The presence of the nitrates accounted for the nitrogen in the gases that were derived from the mineral.

Professor H. How obtained strong acid fumes on igniting manganese from the Tenny Cape mine, Nova Scotia.†

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* Comptes Rendus Acad. Sci., Vol. I., 1860, p. 868.

† London, Edinburgh and Dublin Phil. Mag., Vol. 31, p. 169.

CHAPTER VI.

THE BATESVILLE REGION OF ARKANSAS.

DISTRIBUTION OF MANGANESE IN ARKANSAS.

Manganese ores occur in two different parts of Arkansas, one in the Batesville region, mostly in Independence and Izard counties, in the northeastern part of the state; the other in the southwestern part of the state, in the region extending from Pulaski county on the east to Polk county and the Indian Territory border on west. In the former region considerable mining has been done; in the latter the amount of work has been limited. The two regions approach, in their nearest parts, within about 90 miles of each other, the southern extension of the Batesville region being about that distance northeast of the manganese area of Pulaski county, while it is over 150 miles northeast of the manganese area of Polk county.

The ores of the Batesville region occur in a residual clay, derived from the decay of a limestone which has been placed, chronologically, by Professor Henry S. Williams, in a position intermediate between the Trenton and the Niagara horizons of the Silurian section of New York; the ores of southwestern Arkansas occur in novaculite (a siliceous rock) which is in all probability of Lower Silurian age, but of somewhat doubtful position in that series.* The limestone of the northern part of the state dips in gentle monoclines to the south and southwest;

* Graptolites collected up to the present time (January, 1891), by Mr. L. S. Griswold, of this Survey, in rocks associated with the novaculite have been determined by Professor Henry S. Williams and by Dr. R. R. Gurley as mostly of Trenton age, though those from one locality were determined by Dr. Gurley as of Calciferous age. See the forthcoming report by Mr. Griswold on the novaculite region, Vol. III., of the publications of this Survey for 1890.

the novaculite of the southern part of the state is greatly disturbed and exists in a series of east and west folds. Between the two areas, there is a great series of Carboniferous and Lower Carboniferous rocks, occupying the valley of the Arkansas River and comprising the mass of the Boston Mountains to the north. To the north of the Batesville region, and dipping under it, is a series of rocks belonging to the Calciferous formation of the Lower Silurian. Both manganese regions are cut off on the east by the Tertiary, Pleistocene and Recent sediments of the Mississippi valley.

The paleontology of the manganese regions is not as yet known in sufficient detail to attempt to trace out the relations of the two ore-bearing horizons, but the wide lithologic difference between the limestone from which the ore is derived in the northern part of the State, and the novaculite, composed of almost pure silica, which contains the ore in the southern part of the state, is a noteworthy fact.

The manganese ores in both regions are in the forms of the various oxides of the metals.*

PREVIOUS GEOLOGIC INVESTIGATIONS IN THE BATESVILLE REGION.

A detailed account of the geologic investigations made in Arkansas previous to the explorations of the present Survey, will be given in a forthcoming report by Dr. J. C. Branner, State Geologist. The statements made below, therefore, are intended only as a brief summary of the principal explorations that have heretofore been made in that part of northeastern Arkansas included in the Batesville manganese region.

Previous to the present investigation the only work of a geologic nature that had been published concerning this area was that of Dr. D. D. Owen,† former State Geologist of Arkansas, and his assistant, Edward T. Cox, in 1858. Analyses and descriptions of the manganese ores were also given by Dr. Wm. Elderhorst, chemist of the Survey.

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* For further details, see description of each region.

† First Report of a Geological Reconnoissance of the Northern Counties of Arkansas, 1857-1858.

As early as 1834, G. W. Featherstonhaugh,* United States Geologist, passed from Missouri southward through what was then the Territory of Arkansas, to Texas. His course from Missouri lay from Wayne county, in the southeastern part of that state, across the St. Francis and Black Rivers to the White River valley, and thence southwest across the valley of the Arkansas River. He describes the lead and zinc ores of Missouri and refers to the occurrence of the manganese in the southeastern part of that state.† He does not, however, mention the existence of manganese in northern Arkansas and it is probable that his route lead him through the country immediately east of the part of the state containing those ores. At that early date the existence of manganese was not known in northern Arkansas and the expedition was made to obtain a general knowledge of the nature of the region and not to attempt any detailed investigations.

Owen, in his survey already referred to, described the occurrence of the manganese ore in several localities on Lafferty Creek in the western part of Independence county,‡ and his assistant, Edward T. Cox, describes the ore on the Cason property, three miles north of Batesville.§ No detailed investigations, however, were made on the subject. Their observations were confined to a cursory examination of the region, such as was unavoidable in the general reconnoissance of the state made by that survey. This kind of work was a necessary preliminary to a more thorough study of different districts, and though it gave only a limited amount of detail, it afforded a general idea of the different parts of the state.

Owen refers the manganese ores chiefly to the "cavernous subcarboniferous limestones," || but the investigations of the present survey have shown that the ores occur in a residual clay derived from the decay of a Silurian limestone. This formation contains fossils which have been determined by Professor Henry

* Geological Report of an Examination made in 1834 of the Elevated Country between the Missouri and Red Rivers. Washington, 1835.

† Ibid., page 54.

‡ First Report of a Geological Reconnoissance of the Northern Counties of Arkansas, 1857-1858, p. 39.

§ Ibid., p. 221.

|| Ibid., p. 136.

S. Williams, of Cornell University, as belonging in some places to the Trenton and in others to the Niagara of the New York section. It is designated in the present report as the St. Clair limestone, and is overlain by a series of cherts and limestones, designated as the Boone chert. The latter formation was also included by Owen in his Lower Carboniferous series, and the examination of the fossils from it by Prof. Williams has corroborated its Lower Carboniferous age. The chert series caps the St. Clair limestone throughout the region in question, and loose fragments of it usually cover the slopes of the latter formation. The St. Clair limestone has also, in many places throughout the manganese region, been very extensively decayed and the overlying chert has been let down in a broken mass on top of the residual clay and ore, often completely obscuring any parts of the original limestone that may have been preserved. Consequently, the fact that Owen included both the chert and the St. Clair limestone together as Lower Carboniferous, is probably to be attributed to an accidental oversight due to his hasty trip. Above the Boone chert are a series of shales, sandstones and limestones, including the Fayetteville shales, Batesville sandstone and other formations mentioned later on in this chapter, which were correctly determined by Owen as Lower Carboniferous.

Below the St. Clair limestone, occurs a massive blue limestone, the Izard limestone of this report, which was also included both by Owen and Cox in the Lower Carboniferous; but its position below the St. Clair limestone now makes this determination untenable and proves its Silurian age. Well preserved fossils are rare in this formation, and to this is probably due the determinations of Owen and Cox, since, in an examination such as they made, which was necessarily of a hurried and general character, they were compelled to draw certain conclusions without the assistance of local details, and hence the possibility of error. Below the Izard limestone, Owen describes a series of magnesian limestones, sandstones, "calciferous sandrocks" and cherts, which were determined by him as belonging to the Lower Silurian. This correlation has been corroborated by the exam-

inations of Professor Henry S. Williams who has since identified the series as belonging to the Calciferous formation of the Lower Silurian.* (See page 112)

The annual reports of the Mineral Resources of the United States from 1883 up to the present time have given statistics of production of Batesville manganese ores and brief accounts of the operations of the various companies. The first of these statements was written by Dr. David T. Day in the report for 1883–4, and since then they have been written by Mr. Jos. D. Weeks.

In 1886 Professor F. L. Harvey, of the Arkansas Industrial University at Fayetteville, published a pamphlet entitled The Minerals and Rocks of Arkansas. In it he states the existence of pyrolusite, braunite, psilomelane and wad in Independence county, but gives only a brief, general description of them.

Beyond the work already mentioned, little or no further investigation of the Batesville region has been published, though many short accounts of the manganese ores have been given at different times in various periodicals and official state documents. In addition, numerous private reports on various properties have been made to mining companies, but have necessarily been confined in their circulation. The most extended of these was that made in 1885 by Mr. John Fulton, of Johnstown, Pennsylvania, to the Keystone Iron and Manganese Company.

THE POSITION OF THE BATESVILLE REGION.

The manganese region of northern Arkansas, as shown in the map accompanying this volume, lies in the northeast part of the state and in the valley of the White River. It occupies the northwest part of Independence, the southeast part of Izard, and the eastern corner of Stone counties. It is situated from three to twelve miles north and northwest of the town of Batesville, and has long been known as the *Batesville region*. This name is retained here not only because the town is the largest in that part of the state, but, as a shipping point and as a source of supply, it has long been identified with the manganese industry.

* This subject is discussed in full in the report of Dr. J. C. Branner, State Geologist, in Vol. I. of the reports of the Survey for 1889.

The manganese area, as thus defined, is about seventeen miles long in an east and west direction, its longest axis being on the line between townships 14 and 15 north. It is 7 to 9 miles wide in a north and south direction, the widest part being along the valley of Polk Bayou. These boundaries include about 122 square miles. It is not to be inferred, however, that manganese is to be found everywhere in this area. The region defined above simply represents the part of the country in which manganese occurs at varying intervals. The ore in any one place may or may not be in paying quantities, as will be hereafter explained.

HISTORY OF MINING IN THE BATESVILLE REGION.

The existence of manganese in the Batesville region has been known for over forty years, but it has only been since 1881 that the ore has been mined to any considerable extent. Col. Matt. Martin, of Batesville, was the first to discover the value of this ore, and between 1848 and 1850, he and Mr. M. D. Fields acquired large tracts of land in the manganese region. This was done on the advice of Professor Gerard Troost, who was then State Geologist of Tennessee. Col. Martin worked some of these lands to a limited extent, and as early as 1850-1852 shipped small quantities of ore to Boston, New York and Philadelphia. One shipment is also said to have been made to Liverpool, where it was used at the chlorine works of Charles Tennant, in Glasgow. At this early date, however, there were no railways in the state and the ore could be brought to market only by hauling in wagons to the White River or Black River, and shipping by barge to the desired destination. The ore mined by Col. Martin was taken to New Orleans in barges and shipped thence by sea.

For over twenty-five years after Col. Martin's first shipments, occasional small quantities of manganese were mined in the Batesville region. The ore shipped during this period was mostly, if not altogether, used for chemical purposes and not in the manufacture of steel, which today consumes the whole production of Arkansas. A few hundred tons would probably include the total quantity produced up to 1868. In that year Mr. Wm. Ein-

stein, of St. Louis, made the first shipment of manganese from Arkansas for steel purposes. It was sent to Messrs. Schoenberger and Company, Juniata Iron Works, Pittsburg, Pennsylvania. The ore was shipped by barge down the White River, thence to the Mississippi, and up the Ohio to its destination. The total quantity amounted to ten tons, which was sold at Pittsburg for $30.00 per ton. At that time, however, the production of steel in the United States was very small compared with its present manufacture, and the demand for manganese was correspondingly less than at present.

For twelve years after Mr. Einstein's shipment, little or no mining was done in the Batesville region. The test of Mr. Einstein's ore is said to have proved a success, but the comparatively small demand for manganese at that time was mostly supplied from Virginia, Georgia, and foreign sources. Moreover, there was still no means of railway transportation in the state, and it was not until 1871–1872, when the St. Louis, Iron Mountain and Southern Railway was extended south from the Missouri line to Little Rock, that shipping facilities were obtained. Even then, Newport was the nearest railway point, and it was thirty-five to forty miles distant from the manganese region. The ore had to be shipped by barge to that place and there transferred to cars. It was not until 1886, when the Batesville branch line was extended to the manganese region, that the ore could be shipped all the way by rail.

In 1881, Mr. E. H. Woodward, representing the Ferro-Manganese Company, started operations in Arkansas. Mr. Woodward had already become identified with the Georgia manganese region, and was well known in all the other manganese localities of the Appalachian Mountains. He bought and leased tracts of land in the Batesville region, and from then until 1887 mined intermittently, shipping altogether, probably about five thousand tons or more of ore. A large part of this came from the Southern, the Turner, the Trent, and the Montgomery mines.

At the time Mr. Woodward began his operations, the demand for manganese for use in steel was rapidly increasing, and the output of his mines, representing as it did, the first systematic

production of manganese in the Batesville region, found a ready sale.

In October, 1885, the Keystone Iron and Manganese Company, of Pennsylvania, acquired large tracts of land in the Batesville region. They commenced operations on the Southern Hill and have worked continuously ever since. They are the largest operators in the region and have probably mined over a half of the ore that has been shipped from Arkansas. Their total production, since they commenced work until December 31, 1890, has been 18,111 tons.

In the same year (1885) the St. Louis Manganese Company, of St. Louis, Missouri, was organized and commenced work in the region north of Cushman, and elsewhere. They mined, up to September, 1890, 1,700 tons of ore. About the same time, the Missouri Furnace Company, of St. Louis, acquired manganese lands in the Lafferty Creek district, but their work has been limited. The total output up to September 1, 1890, was a little over 500 tons. Besides these companies, others commenced operations at or near the same time, but their production has been small. Among them were the American Manganese Company, the White River Manganese Company, the Arkansas Manganese Company, and the Blair Mining Company, as well as others.

The extension, in 1886, of the Batesville branch of the St. Louis, Iron Mountain and Southern Railway, from Newport, through Batesville, to Cushman, has greatly facilitated the transportation of the manganese ores, and has opened up mining localities which would otherwise have been inaccessible. In 1888, Messrs. Abbot and Ring, of Chicago, opened up properties on Polk Bayou. Later, the firm was changed to Skinner and Abbot, and in 1889 it was again changed to John B. Skinner and Company. Mr. Skinner has erected a large washer on Sullivan Creek, and energetic arrangements are now being made for the extensive mining and treatment of the manganese ores of that part of the Batesville region. The production of these firms from April 20, 1889, to June 26, 1890, was over seven hundred tons.

Besides the companies already mentioned, occasional shipments of manganese ore have been made by private individuals, among whom are H. M. Hodge, R. R. Case, I. N. Reed, J. P. Montgomery, John W. McDowell, A. A. Steele, Wm. Reves, J. B. Gray, Messrs. Pritchett, Russell, Drake and others. These shipments, however, were small and a few thousand tons would cover the aggregate amount.

Correct figures of the total amount of manganese mined in the Batesville region are difficult to get, except since the time the ore has been shipped by rail. The records of the ore shipped by barge down the White River, before the railway was extended to Batesville, were either not kept at all or have been lost. It is probable, however, that the total amount of manganese shipped from the Batesville region, from the time mining was first begun, until December 31, 1890, does not exceed 35,000 tons and is between that and 30,000 tons. This production is small compared with that of Virginia and Georgia, but it must be remembered that the latter places have been worked for a much longer time than the Batesville region, that over nine tenths of this production was mined between 1881 and 1890, and that the Batesville region has only in the last four years (1886-1890) had suitable railway facilities.

THE TOPOGRAPHY OF THE BATESVILLE REGION.

Prominent Features.—The prominent topographic features of the Batesville manganese region and the surrounding country, are the Boston Mountains, forming the southern barrier of the White River valley and running northwest and southeast; the rugged chert region running parallel to them on the north side of the river; the rolling sandy country still further to the north; and the low flat woods region, which, to the east, cuts off the mountainous and hilly areas very abruptly. This last region extends thence seventy miles or more to the Mississippi, and represents the westerly extension of the old flood plain of that river.

Erosion.—The topography of the mountainous area is most strikingly dependent on the geologic structure of the country

and on the nature of the different rocks. The whole region is the remnant of an ancient highland, sloping gently to the south and southwest, at angles of from less than 1° to 3°, and occasionally dipping off in steeper monoclines at angles of from 10° to 20°. This simple topography has, however, undergone great change under the denuding influence of atmospheric agencies. The water courses have cut deep channels, which have steadily increased in number and size as the surface exposed to erosion has increased, and, as a result, the steep ravines of parts of Polk Bayou, Salado and Lafferty Creeks and numerous smaller streams have been formed, besides the wider channel of the upper part of the White River. Subterranean erosion has also had its influence in the configuration of the country: the limestones in many parts of the region have been honeycombed by caverns and underground water courses, and in places the gradual leaching away of the limestones has let down the overlying and less easily attacked strata, causing a characteristic topography which will be described more fully in the succeeding chapter.

As a result of all this erosion, the region now presents a series of rugged hills rising 800 to 1000 feet above the sea level and 400 to 600 feet above the surrounding drainage, at times showing gently undulating slopes, at others rising up in conical peaks, or forming flat-topped hills, in which the remains of the former continuous table-land structure still exist.

Boston Mountains.—The Boston Mountains skirt the south side of the White River, and, in the region south of Batesville, rise from 500 to 600 feet above its waters. Sometimes they abut directly on it, forming steep bluffs in which the gently dipping rocks are clearly defined, and at others they recede from it, giving room for small areas of alluvium. This escarpment represents the northern face of the Boston Mountains and is the most striking feature in the topography of the country. It marks, in a general way, the course of the White River from the Missouri line, in Boone county, to the lowlands of the Oil Trough Bottom and Newport. South from their north face, the mountains slope off much more gently in a high, flat country forming the southern part of Independence county. Viewing the Boston Mountains from

tne north, they loom up as a long, flat-topped range of remarkably uniform height wooded with a heavy growth of oak and pine.

Chert Region.—To the north of the White River, the general level of the country gradually rises into an area of rugged chert-capped hills reaching from 100 to 400 feet above the surrounding drainage. This is a barren region, strewn with loose fragments of chert and characterized by a very abrupt and angular topography. In its northern part, erosion has cut through the chert, and the underlying limestones and sandstones have been exposed, giving rise to a less abrupt topography, and representing the region where manganese occurs. This area is characterized by long, tortuous ridges, following the courses of the streams and by rounded knobs, both usually capped by chert and exposing the limestones and sandstones on their lower slopes. To the west, the chert-capped hills gradually blend into the still more rugged country of Marion and Baxter counties; to the east, they are abruptly cut off by the low, flat area of the Black River bottom.

Divide of the White and Strawberry Rivers.—To the north of the chert area, the general level of the country still continues to rise, though the region is not so rugged as that to the south, and, therefore, presents a less imposing appearance. The country is characterized by undulating hills with occasional steeper slopes, and extends thence to the height of land between the waters of the White and Strawberry Rivers.

Rivers, springs and lakes.—The whole of the region already described is well watered by many creeks, all draining into the White River. The latter is navigable up to Batesville at almost all times of the year, and, at high water, it can be navigated for over two hundred miles above that town.

Springs are very numerous in the limestone region, where they gush out of the sides of the hills, often in sufficient volume to afford water power for grist-mills. The Big Spring, six miles northwest of Batesville, and Luster's Spring, six miles west of Batesville, are examples of such water powers. Besides these, many smaller springs are found, such as Blowing Cave and

Phelps' Springs, near Cushman; Cave Spring, on Polk Bayou; and innumerable others. Lakes are nowhere found in the highland region, but in the lowlands to the east, deep sloughs are numerous.

STRUCTURE OF THE BATESVILLE REGION.

Monocline.—The general structure of the Batesville region is that of a broad monocline dipping at low angles, averaging probably less than one degree, to the south and southwest, and finally disappearing under the Carboniferous rocks of the central part of the state. Locally, the rocks often assume a position different from this general structure, and a gentle northeasterly dip or small, low anticlines and synclines are not of unfrequent occurrence. Such disturbances, however, are very limited in their extent, and in their influence on the general features of the country. Local monoclines, dipping off at angles of from 5° to 20°, to the south are of frequent occurrence, and are often persistent for considerable distances in the direction of the strike of the rocks. In fact, the grand monoclinal structure of the region may be said to be made up of these local monoclines connected by areas of more gently sloping or even horizontal strata.

Faults.—Faults have been observed in several places in the region under discussion, but a throw greater than from 100 to 250 feet has not yet been observed. A line of weakness appears to exist at or near the line of parting between the Batesville sandstone and the Boone chert. Sometimes a fault occurs at this point, and at other times there is an abnormally steep dip of 12° to 20°. The faults, in places, blend into the steep dips, and the latter seem to represent simply a tendency towards, or initial stage of the former. Sometimes, as on the lower part of Polk Bayou, this line of weakness is represented by two faults, striking at low angles to each other, and frequently appearing to run together again a short distance beyond.

On Polk Bayou, north of Batesville, where the line of contact of the Batesville sandstone and the Boone chert crosses the stream, two faults are observable, about a half a mile or less apart and running, probably, in a general east and west, or north-

east and southwest direction. In the more southerly one, the level of the top of the Boone chert is above the level of the top of the Batesville sandstone. The exact amount of throw here is doubtful, but it is over 100 feet, as can be seen in the bluffs of the bayou. In the second fault, which is to the north of this one, the central part of the St. Clair limestone is on a level with the base of the Boone chert. The amount of the throw here is about 65 feet. The accompanying figure shows the relation of these faults.

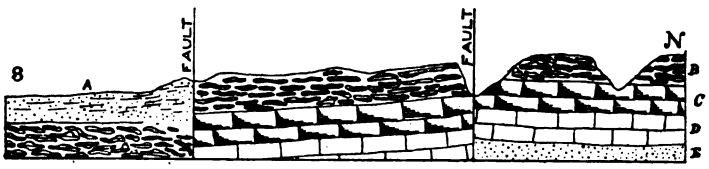


Figure 2. *Section showing faults on Polk Bayou.*

A. Batesville sandstone.
B. Boone chert.
C. St. Clair limestone.
D. Izard limestone.
E. Saccharoidal sandstone.

Horizontal scale: 1 inch—½ mile. vertical scale: 1 inch—600 feet.

At the Cason manganese mine, a little over a mile to the northeast of the Polk Bayou faulted area, there is another fault, in which the lower part of the St. Clair limestone is on a level with the top of the Batesville sandstone. The amount of throw here is over 200 feet and, probably, not less than 250 feet. The Cason fault runs in a general southwest direction, and it seems possible that it is the continuation of one, or the combination of both of the Polk Bayou faults. It will be further mentioned under the head of the Cason mine.

To the east and west of the faulted areas just mentioned, the line of weakness has not yet been carefully examined; but steep dips and areas of possible faulting have been seen at different points along it, and further investigation may prove it to be an intermittent series of steep dips occasionally breaking off into local faults. It is especially possible that faults, like those just described, may occur on Lafferty Creek, near its mouth, and on the

White River, between Penter's Bluff and the mouth of Lafferty Creek. As a result of the existence of this line of weakness, the contact of the Batesville sandstone and the underlying shales with the Boone chert, is often marked by a series of chert ridges running parallel to the direction of the faults, or to the strike of the steep dips, and rising up somewhat abruptly from the less rugged area of the sandstone and shales.

THE AGE OF THE ROCKS OF THE BATESVILLE REGION.

The rocks of the Batesville manganese region and the surrounding country represent formations of Silurian and Carboniferous ages, cut off abruptly on the east by Teritary and Post-Teritary deposits. The sequence of the formations of the Silurian and Carboniferous is shown in the accompanying columnar section. The paleontologic determinations on which the divisions in the section are based were made by Professor Henry S. Williams, of Cornell University, and are given in detail by Dr. J. C. Branner, State Geologist, in Volume I. of the reports of the Survey for 1889.

The lowermost rocks found in the region are a great series of sandstones, sandy limestones and more or less dolomitic limestones, considered by Dr. Williams to represent the Calciferous group of the Lower Silurian. They border the manganese region on the north and extend thence into the extreme northern part of the state. Above them is a massive blue limestone reaching a maximum thickness, in the manganese region, of over 280 feet, and designated as the Izard limestone. It is extensively developed to the south of the area of the Calciferous rocks. Immediately overlying this, is a bed of highly crystalline limestone, reaching a maximum thickness of over 150 feet and designated as the St. Clair limestone. This formation is the source of the manganese ores in the Batesville region, as will be explained more fully in chapter VIII., and is extensively developed throughout the manganese area. It contains a fauna which has been determined by Dr. Williams as belonging, in some places, to the upper part of the Lower Silurian age, corresponding to the Trenton limestone of the New York section, and in others to an epoch

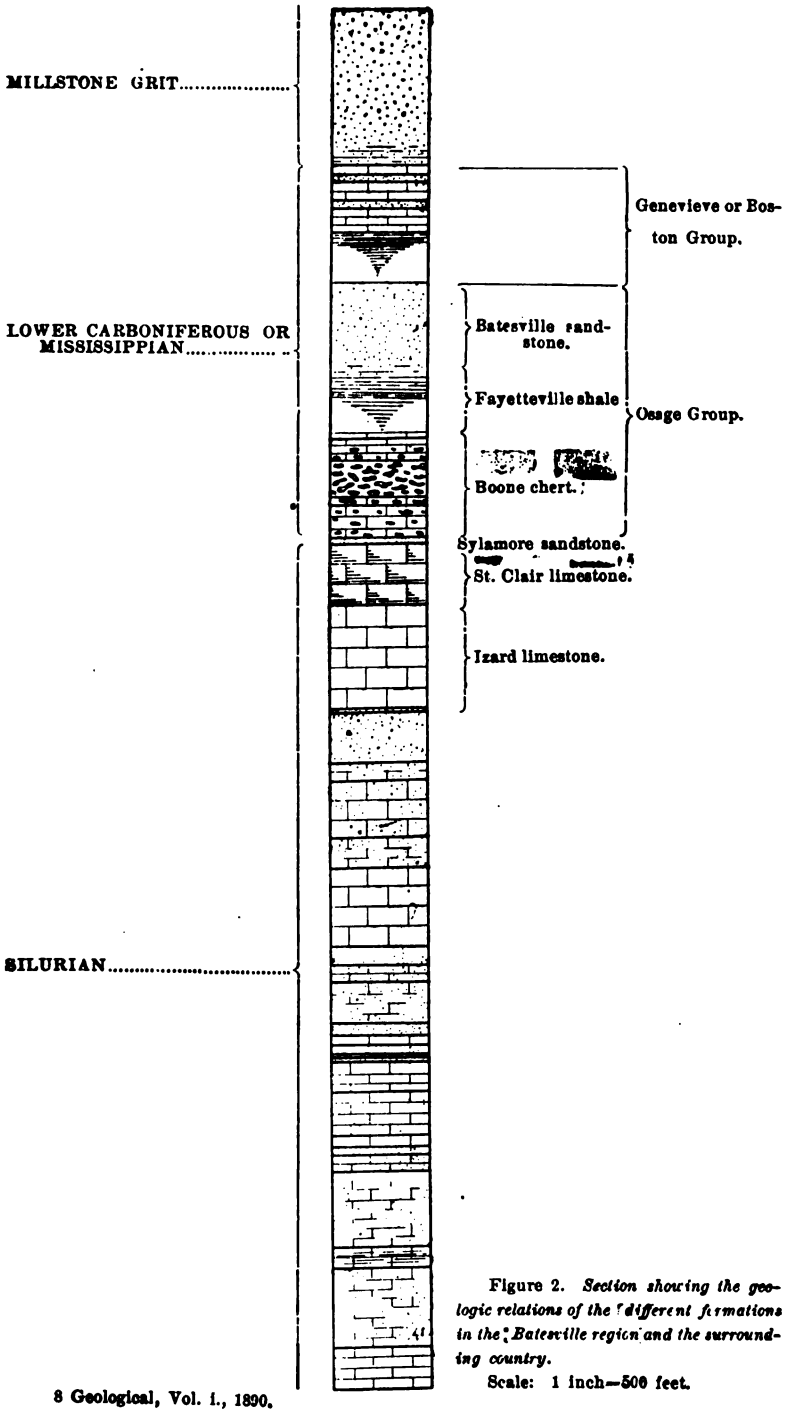


Figure 2. *Section showing the geologic relations of the different formations in the Batesville region and the surrounding country.*

Scale: 1 inch—500 feet.

intermediate between the Trenton and the Niagara. Fossils collected on Polk Bayou, four miles north of Batesville, have been determined by him as undoubted Trenton forms; while fossils from St. Clair Springs, eight miles northeast of Batesville, and from elsewhere in the country to the west, are considered by him to be intermediate between those of the Trenton and Niagara. The bed appears to be continuous, and Dr. Williams places it, chronologically, in the latter intermediate position.

Overlying this Silurian terrane, is a bed of yellow, brown or gray earthy sandstone, often containing green or black shaly layers, and sometimes merging into beds of the same material. It is frequently much stained by iron and sometimes contains small flat ferruginous concretions. This deposit is of very irregular distribution, sometimes being entirely absent and at other times reaching a thickness of thirty or forty feet. It is developed on a much larger scale in Stone county and the country to the west, than in the Batesville region, and is described under the name of Sylamore sandstone, by Dr. Branner in the report referred to, and by Mr. T. C. Hopkins.* It is supposed by Dr. Williams to be the equivalent of the "Black shale" of Tennessee and elsewhere in the Mississippi basin (See Dr. Branner's report). It will be further mentioned under the description of the St. Clair limestone.

Above this formation comes a series of Lower Carboniferous rocks capped by the Millstone grit. They aggregate, including the Millstone grit, probably over 1,300 feet and compose the Boston Mountains, † as well as part of the country lying to the north of the mountains. The Lower Carboniferous rocks are named the "Mississippian series" by Dr. Williams, and are divided by him into three groups, which, in ascending order, are the Chouteau, the Osage, and the Genevieve or Boston. The Chouteau, as thus defined, represents the lowermost

* Report on Marbles and Other Limestones, Vol. IV., of the publications of the Survey for 1890.

† These remarks refer only to the eastern part of the Boston Mountains, extending from the eastern borders of Stone and Cleburne counties to Oil Trough Bottom and the lowlands of Newport.

group of the Mississippian, and is not developed, so far as yet known, in northern Arkansas, unless it be by the Sylamore sandstone just mentioned. In Missouri it includes the "Chouteau limestone," the "Vermicular sandstone and shales," and the "lithographic limestone". The overlying Osage group, which includes the "Burlington" and "Keokuk" groups, is represented in the Batesville region by the Boone chert, the Fayetteville shale and the Batesville sandstone. The Boone chert is the lowest member of this group, and includes a series of interbedded cherts and limestones. Dr. Williams,* in speaking of the age of this chert horizon, says, "Stratigraphically, it appears to be the equivalent of the Tennessee Siliceous group, and of the Encrinital and Archimedes limestones of the Missouri classification. Paleontologically, it includes the Burlington limestone of Iowa, and the Lower Archimedes or Keokuk limestone of Hall."

The Boone chert comprises the broken country rising up three miles north of Batesville and running off thence west and northwest in a range of rugged hills, in the general direction of the White River. Above the Boone chert, is the Fayetteville shale, which appears on the surface along the southern border of the chert area. It is especially well developed east of Batesville, in Independence county, in the neighborhood of Moorefield and Sulphur Rock. The Batesville sandstone, which forms the uppermost member of the Osage group, extends from north of Batesville southward, through that town, across the White River valley, and finally disappears at the foot of the Boston Mountains under the members of the Boston group.

The Boston group includes the series of shales, limestones and sandstones reaching from the top of the Batesville sandstone to the base of the Millstone grit, and representing the upper part of the Lower Carboniferous, or Mississippian of Dr. Williams' classification. The name Boston group has been applied by Dr. Branner from the fact that these formations comprise the mass of the Boston Mountains.

It is not within the scope of this volume to treat all the

* See report by Dr. J. C. Branner, State Geologist, Volume I. of the publications of the Survey for 1889.

members of the large series of Lower Carboniferous and Calciferous rocks of the Batesville region in full, but only to the extent to which they are connected with the occurrence of manganese ores. The St. Clair limestone, the overlying Boone chert, and the underlying Izard limestone are intimately connected with the occurrence of these ores, and and will be treated in detail. In order, however, that the relation of these formations to the overlying and underlying rocks may be better understood, a short summary of the latter will be given later in this chapter.*

THE CALCIFEROUS FORMATION.

Nature of the Calciferous rocks.—As already stated, the oldest rocks in the Batesville region are a large series of sandstones, sandy limestones and limestones of a more or less magnesian nature. Fossils are sometimes found in the limestones, but most of them are badly preserved and generally in the form of calcite casts. The rocks are supposed, however, by Dr. H. S. Williams to belong to the Calciferous formation of the Lower Silurian, and are designated as such on the map accompanying this volume. The larger part of them remain to be studied; only the upper members have yet been carefully examined, and the thickness of the series is, as yet, undetermined. Below them, and exposed to the north of them, is a series of rocks which, according to the observations of Dr. J. C. Branner, consist mostly of dolomites, cherts and quartzites. These run thence northward into Missouri.

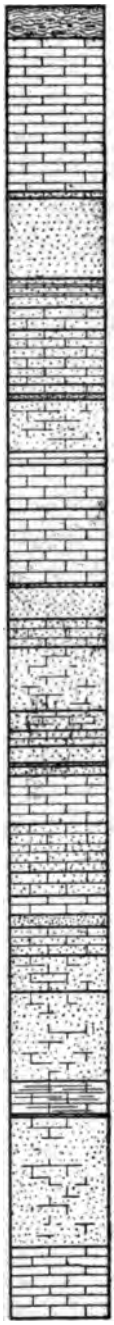
The Calciferous series consists of alternating calcareous and arenaceous deposits, varying from comparatively pure limestones through various stages of sandiness to comparatively pure sandstones. The limestones are massive and vary from gray to brown in color, from hard to soft in consistency, and are generally more or less magnesian. The sand frequently found in them is in the form of transparent grains, varying from very fine to com-

* For further details of the Lower Carboniferous rocks of northern Arkansas, the reader is referred to the report of Dr. J. C. Branner, State Geologist, in Vol. I., of the publications of the Survey for 1889, and to the report of Professor F. W. Simonds on Washington county in Vol. IV., of the publications of 1888.

paratively coarse. The sandstones are composed of white or transparent grains varying in size in the same way as the sand in the limestones. Sometimes these beds are soft, and readily disintegrate, on exposure, into a white sand. At other times they are much harder and gradually merge into quartzite. Frequently quartzite occurs as an interstratified bed, though elsewhere it is found in irregular masses, enclosed by the softer sandstone, and blending into it both laterally and vertically. Iron pyrites is a frequent constituent of many of the beds, and the brown hematite ores of the country about Smithville and Powhatan belong in the rocks of this series.

The section of the Southern mine well.—At the Southern mine, near Cushman, in Independence county, the lower 1,750 feet of a well boring 2,040 feet deep passed through rocks of the nature described,* but did not reach the underlying cherts. This boring gives the most detailed information, as regards the sequence of the strata it passed through, that is at present obtainable. Samples were saved wherever the nature of the rock changed during the boring and were carefully labelled. By the kindness of Mr. S. R Kennedy, Superintendent of the mine, the Survey was enabled to examine them and compile the accompanying columnar section. The strata either lie horizontally or dip at very low angles, so that the thickness obtained from the boring very closely represents the actual thickness of the beds. The samples were in the form of powder or sand, such as is brought up in the "slimes" of an ordinary punch drill, and therefore the exact structure of each member, and in certain cases the relative proportions of sand and limestone, are sometimes a little doubtful. But generally a few pieces were found in each sample sufficiently characteristic to show, with the help of a lens, the physical character of the rock. Some of the upper rocks passed through in the boring have also been examined in the field, and

* The limits of the Califerous formation in the region in question have not yet been determined, and, consequently, it is uncertain whether all the rocks passed through in the lower part of the Southern mine well are to be included in this formation, or whether some are still older. Therefore no attempt at a division is made here, and the accompanying well section is given simply to illustrate the nature of rocks which it passed through and not with the intention of necessarily grouping them together.



	Feet
Detritus	50
Izard limestone	240
Sandy limestone	10
Saccharoidal sandstone	125
Interbedded gray limestones and sandstones, with calcareous sandstones	45
Massive, gray and brown limestone with disseminated grains of sand.	38
Massive, gray limestone, with disseminated grains of sand (82 feet) running into a chocolate-brown limestone with similarly disseminated grains of sand (15)	97
Slightly calcareous gray sandstone	9
Highly calcareous gray sandstone	82
Massive, chocolate-brown and gray limestone	19
Massive, gray limestone	70
Massive, gray limestone, harder than the last	115
Slightly sandy, gray limestone (4 feet) passing at its base into a white sandstone (51 feet)	55
Sandy, dark gray limestone	45
Fine grained, calcareous, gray sandstone becoming coarser at the base	130
Massive, gray limestone with disseminated grains of sand	25
Fine grained, white sandstone	25
Sandy, gray limestone running into fine grained white sandstone	20
Massive, chocolate-brown limestone	75
Massive, gray limestone with disseminated fine grains of sand	75
Massive, gray limestone with disseminated coarser grains of sand	30
Massive, gray limestone	30
Fine grained, white sandstone	20
Massive, gray limestone with disseminated grains of sand	45
Fine grained, calcareous, gray sandstone	55
Fine grained, calcareous, white sandstone	140
Shaly, gray limestone with thin strata of green shale, passing at its base into a shaly, calcareous sandstone (2 feet)	52
Very fine grained, calcareous, gray sandstone, with thin strata of black shale	200
Creamy-gray limestone to the base of boring	115
	2040

Figure 8. *The section of the Southern mine well-boring.* Scale: 1 inch=300 feet.

thus further information has been obtained regarding their nature.

1. The well boring was started on the slope of a hill, and the first fifty feet that were passed through consisted of fragments of chert and limestone buried in residual clay.

2. Below this detrital deposit is a thickness of 240 feet of the Izard limestone. This formation will be described later in this chapter.

3. At the base of the Izard limestone, is a bed of sandy limestone, 10 feet thick. This represents the transition between the limestone and the underlying saccharoidal sandstone. These two beds rarely come together in sharp contact, but are almost always separated by this transitional stratum. It is frequently seen on the slopes of the hills and is composed of massive blue limestone, becoming more and more sandy as it approaches the sandstone, and varying from two to ten feet in thickness. Sometimes thin layers of pure limestone and of pure sandstone occur in this stratum, but most of it is simply a more or less even mixture of sandy limestone. In the Izard limestone, just above its contact with this bed, there are frequently found concretionary masses of hard gray chert, three to eight inches in diameter. They have an oval shape, a distinct concentric structure, a marked conchoidal fracture and a vitreous lustre.

4. Immediately below the transitional bed just described, is a friable, white saccharoidal sandstone 125 feet thick. This crumbles very readily on exposure into a loose fine sand. Sometimes strata of a very characteristic light, watery-green color, and of the same sandy consistency are interbedded with it. These doubtless owe their color to the presence of proto-salts of iron, since, on an exposed surface, the green color changes to a yellow or brown and the rock becomes coated with a ferruginous crust from an eighth to one inch in thickness; while inside this covering, the original green color remains. Iron pyrites, in disseminated crystals and nests of crystals, is a frequent constituent of the bed, and on an exposed surface it also is oxidized and shows itself in rusty blotches on the rock. Though the normal color of the sandstone is white, this rusty

stain is very characteristic in many places, and it is rare that any large areas of the bed are seen without being partly discolored on the surface. The stain is especially noticeable in the bedding planes; and in many creek bluffs ferruginous springs issue from these lines and cover the surface of the rock with a rusty coating of hydrous peroxide of iron.

This sandstone occurs in strata of different thicknesses varying from a few inches to several feet. Falsebedding is of very frequent occurrence, and, in many places, layers of false-bedded sandstone are interbedded with layers of the same rock horizontally bedded. Ripple marks are also of frequent occurrence on the bedding planes of the rock.

The rock, as a whole, is of uniform structure, though some of the strata approach a quartzite in form, and are harder than others, thus causing the weathered surface to show protruding and receding lines. In many places the whole mass of the rock is cut up by a net-work of seams of white quartz from an eighth to a half inch in thickness. Where such an occurrence is exposed to weathering, the sandstone disintegrates much faster than the quartz and the latter protrudes from the rock, giving it a honey-combed appearance.

The saccharoidal* sandstone is eroded in a very irregular and very characteristic manner. The accompanying figure represents a weathered surface on the east side of Polk Bayou, ten miles north of Batesville. It is on the slope of the hill near the

Figure 4. *Section showing the erosion of the saccharoidal sandstone.*
Horizontal and vertical scale: 1 inch=30 feet.

bed of a small creek channel. The table-shaped mass rising up on the left hand shows the layers of false-bedded sandstone.

*The term *saccharoidal* is used here simply to designate the nature of the sandstone in question, and not with any intention of correlating it with the Saccharoidal sandstone of the Missouri classification. The geologic relations of the two formations have not yet been determined.

On the Batesville and Powhattan road, twenty miles northeast of Batesville, the sandstone underlies a gently rolling country, and, at frequent intervals, its eroded surface protrudes through the sandy soil in the form of low knobs and mushroom-shaped bosses.

Below this sandstone is a series shown in the well section to be 45 feet thick, and composed of thin beds of sandstone and limestone. The sandstone is sometimes of the soft, pulverulent variety just described, but is usually much harder, and often occurs in the form of a quartzite, in which the separate grains of sand have sometimes been almost entirely obscured. Such rock often caps small hills, and some of it very much resembles the chert of the country to the south, lying, as it does, in rough, broken, angular fragments on the hilltops and slopes. The conversion of the sandstone to quartzite has taken place very irregularly, and the two rocks blend into each other both laterally and vertically. Frequently irregularly shaped masses of sandstone are enclosed on all sides by the quartzite, and, conversely, masses of quartzite are often enclosed on all sides by soft sandstone. Such phenomena as these evidently point to the local formation of hydrous silicic acid in the interior of the sandstone beds, though the chemical processes by which this has been brought about have not yet been sufficiently studied to satisfactorily explain such occurrences. Frequently, also, nodular masses of chert, one to ten inches in diameter, of a gray or black color, with a distinct concretionary structure and a conchoidal fracture, are found in the sandstone strata. The limestone strata are of a light or dark gray color, massive, or, rarely, semi-crystalline and often of a slaty structure, splitting into slabs from a half inch to three inches in thickness.

The remaining rocks passed through in the well boring at the Southern mine have not been sufficiently studied in the field, to afford further details than have already been given on the columnar section.

THE IZARD OR BLUE LIMESTONE.

Name.—The name Izard has been applied to this formation by Dr. J. C. Branner, State Geologist, on account of its extensive

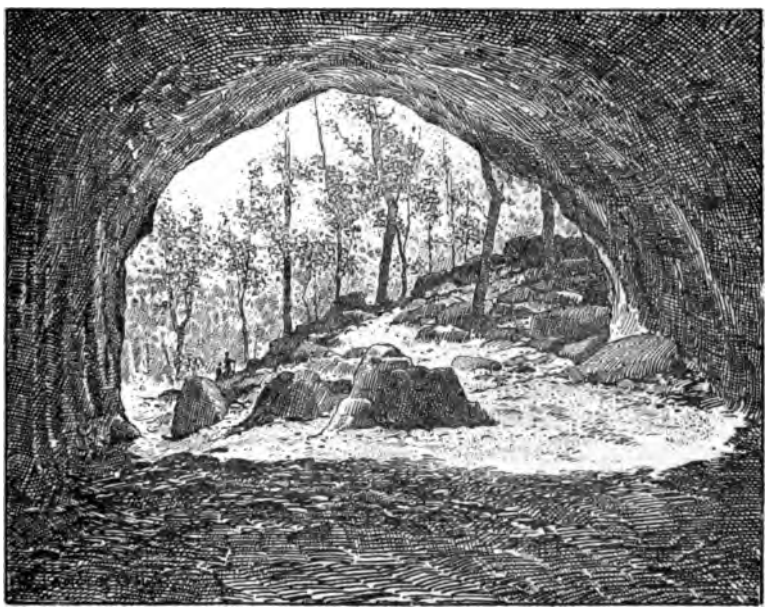
development in the southeastern part of Izard county. In Penter's Bluff, on the White River, in this county, it reaches a thickness of 280 feet (barometric measurement), which is the maximum observed for it in the manganese region.

Nature of the Izard limestone.—The limestone is a massive, blue or grayish-blue rock, sometimes, though rarely, assuming a finely granular semi-crystalline structure. The weathered surface frequently shows very irregular spots and lenticular seams of a buff-colored earthy appearance, varying from one sixteenth to one half inch in thickness, and very much like some of those seen in the Lower Silurian limestones of Virginia.

Lithographic stone in the Izard limestone.—Near the top of the Izard limestone, are frequently found strata of a cream-colored or of a dark watery-blue limestone, with a smooth, even, compact structure and a conchoidal fracture. These vary from 1 to 4 feet in thickness and are separated from each other by strata of the ordinary limestone. Often the creamy and dark colors blend into each other in horizontal layers, forming a beautifully banded rock. Such a material has been worked for lithographic stone in several places, especially at Dr. Warden's quarry, on Lafferty Creek. It is also seen in the Izard limestone on Penter's Bluff, and in places on the divide between Polk Bayou and Sullivan Creek. The objection to the rock for lithographic purposes is that it contains veins of white crystalline calcite, varying from the thickness of a sheet of paper to one-sixteenth of an inch or more, which often pierce it in all directions and render it unsuitable for the finer classes of lithographic work. In places, however, small masses can be obtained which are free from such imperfections, and possibly, further explorations may develop localities where larger pieces can be gotten.

Caves in the Izard limestone.—Caves are of frequent occurrence in this formation, and, although not of very great size, are very numerous and often run far back into the hills, forming a series of chambers connected by narrow passages. Stalactites and stalagmites are sometimes seen.

Thickness of the Izard limestone.—In a general way, the Izard limestone is thicker in the western part of the area represented in



FARRELL'S CAVE, BATESVILLE REGION, ARKANSAS.

A cavern mostly in the Izard limestone, partly in the St. Clair limestone.

the map than in the eastern part, though for short distances this rule will not always hold, as the thickness is very variable, even over limited areas. It has already been stated that the greatest thickness is in Penter's Bluff, where the Izard limestone forms the lower 280 feet of an almost vertical cliff rising 485 feet above the White River. As it is still seen at the foot of the bluff, it probably has a greater thickness. To the northeast of Penter's Bluff, it is exposed in numerous other bluffs on East and West Lafferty Creeks. On Lee's Mountain, in township 15 N., 8 W., section 7, its thickness is 240 feet, and in the well boring at the Southern mine, near Cushman, a similar thickness was found. The bed does not, however, preserve such a development throughout this area, and sometimes it is probably less than half this thickness. On Polk Bayou, two miles above the mouth of Sullivan Creek, and some ten miles, in an air line, east by south from Penter's Bluff, it has a thickness of only 150 feet, this measurement having been taken from the base of a small exposure of St. Clair limestone on top of the hill, to the sandstone, which underlies the Izard limestone, at the foot of the hill. Still further east, in the region of the lower part of Dota Creek and of Walnut Grove, * the Izard limestone is probably as thin, if not thinner, than at the last mentioned locality; but as the hills here are largely covered with gravel, and are much lower than to the west, the exact amount of change is uncertain.

To the west of Penter's Bluff, beyond the western limit of the map, the Izard limestone has been found by Mr. T. C. Hopkins,† of this Survey, to gradually thin out, just as it does to the east, but probably less rapidly.

Fossils in the Izard limestone.—Fossils are occasionally found in the Izard limestone, but they are usually very imperfect and occur as calcite casts of the original remains. The overlying St. Clair limestone, however, has been definitely determined by Dr. H. S. Williams, as belonging to a

* Walnut Grove is not included on the map accompanying this volume, but it lies six miles east of Convenience post office.

† See report by Mr. Hopkins on Marbles and Other Limestones, Vol. IV., of the publications of the Survey for 1890.

horizon between that of the Trenton and that of the Niagara of the New York section, and, therefore, the Izard limestone cannot belong above this horizon. On the other hand, it is underlain by Calciferous rock. Whether it should be included, however, with either the underlying or overlying formations, or whether it marks a distinctive horizon, is as yet uncertain.

Contact of Izard and St. Clair limestones.—At the contact of the St. Clair and Izard limestones, the latter generally shows a tendency towards, or an initial stage of the same crystalline structure as is well developed in the former. This becomes apparent by the presence of transparent calcite crystals scattered through the massive rock. These, though very numerous near the contact line, rapidly decrease with an increase of distance from that line. Such occurrences are not confined to isolated localities, but wherever the contact of the two rocks is seen, this tendency of the massive rock towards crystallization is very apparent, and seems to show that the same agency that enabled the St. Clair limestone to crystallize, also acted, though in a lesser degree, on the Izard limestone.

THE ST. CLAIR LIMESTONE.

The St. Clair limestone will be treated under the discussion of the manganese ores of the Batesville region. Mention of it here is confined to its general character and its relation to the underlying and overlying formations.

Name.—The name St. Clair is taken from St. Clair Spring, which is on the Batesville and Hickory Valley wagon road, eight miles northeast of the former place. The spring is a well known locality, and the name is used here as the bed is the only limestone in the neighborhood and cannot be confused with any other. Elsewhere it is usually exposed with the underlying or overlying limestones, and therefore the use of the name of any such place might give rise to confusion.

Composition of the St. Clair limestone.—The formation con-

sists of a granular crystalline limestone of light gray, pink, chocolate-brown or purplish-black color. It has a maximum thickness of over 150 feet in the manganese region. It contains nodules and interbedded layers of oxides of manganese, and is the source of the manganese ores as they are now found in a residual clay. It sometimes, also, contains strata of an earthy, red, argillaceous or siliceous material, showing the presence of more or less manganese and iron, as well as strata of sandstone.

To the east of the manganese region, in the country along the south fork of Dota Creek, the St. Clair limestone thins out, and finally disappears altogether, or is represented only by a very thin stratum, which is almost invariably covered up by loose chert from above.

The work of Mr. T. C. Hopkins,* in the area to the west of the manganese region, has shown that there also the St. Clair limestone thins out in a manner similar to the Izard limestone, already described. Consequently it will be seen that the part of the Silurian terrane of northern Arkansas comprised in the Izard and St. Clair limestones, reaches its maximum development in the Batesville region, especially in the Lafferty Creek basin and the country immediately west of it.

Fossils in the St. Clair limestone.—Fossils from this formation have been determined by Dr. H. S. Williams as belonging, in some places, to the Trenton and in others to a horizon between the Trenton and Niagara of the New York section. (See page 114). In view of this fact, and also the fact that the overlying Boone chert has been determined as of Lower Carboniferous age, the possibility of an unconformity between the two horizons might be expected. None such has, however, been observed in the manganese region; but Dr. Williams cites facts observed in Boone county, in the northwestern part of the state, by W. P. Jenney, of the United States Geological Survey, as suggesting an uncon-

* See report on arbles and other limestones, Vol. IV., of the publications of the Survey for 1890.

formity between the Silurian and the Carboniferous of that area.*

Contact of the St. Clair limestone and the Boone chert.—The contact of the St. Clair limestone and Boone chert is rarely seen in the Batesville region, as it is usually covered by broken chert. Where it occurs, however, the St. Clair limestone sometimes comes in direct contact with the chert, and at other times there is an intermediate earthy, siliceous deposit, varying from one foot to probably thirty or forty feet in thickness. In township 15 N., 8 W., section 29, the northwest quarter of the northwest quarter, there occurs a rock, which, though it was seen only in loose boulders, probably belongs at the contact of the chert and St. Clair limestone. It is a dark brown or black, earthy, siliceous, soft rock, probably about one foot in thickness and emitting a strong odor on a fresh fracture. At the Southern mine, near Cushman, there are frequently found, at the base of the chert and just above the residual clay, which has resulted from the destruction of the St. Clair limestone, a red, brown or mottled seam of a dry, earthy consistency. It is known by the miners as "ochre," and may possibly represent the former contact of the chert and St. Clair limestone. Elsewhere in the neighborhood of Cushman, and thence westward to Lafferty Creek, there are frequently found loose fragments of a soft buff-colored or rusty-brown material of an earthy or fine sandy structure, frequently containing thin ferruginous seams or flat concretions. The source of these fragments is generally obscured by loose chert, though they are often seen about where the contact of the St. Clair limestone and Boone chert should come, and doubtless sometimes represent the transitional deposit; but the St. Clair limestone itself often contains sandy strata and some of the fragments have undoubtedly come from them. Sections showing the existence of the sandstone in place, both at the contact and in the underlying limestone, are given in chapter VIII. The rock

* For further details see report of Dr. J. C. Branner, State Geologist, in Vol. I., of the publications of the Survey for 1889.

in both places is, in external appearance, the same. On the Batesville and Cushman wagon road, one mile southwest of the latter town, a deposit of this kind, over 20 feet thick, occurs, and probably represents the transitional bed.

At the Meeker place, township 14 N., range 7 W., section 8, in the south half, the contact bed is seen in place. It varies from 6 to 15 inches in thickness, is a compact, bluish-green, earthy rock. It contains small siliceous nodules, an eighth of an inch to one inch in diameter, and small crystals of iron pyrites. White specks, a sixteenth of an inch and smaller, are scattered through it. The material is slightly calcareous and weathers into a brown or buff-colored mass, much softer than the original rock. Its relations to the overlying and underlying formations are shown in the accompanying section. The residual clay in the section is the product of decomposition, in situ, of the St. Clair limestone.

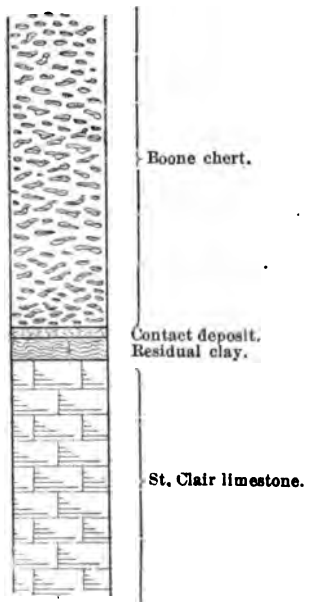


Figure 5. *Section showing the St. Clair limestone and the Boone chert at the Meeker place.* Scale: 1 inch=25 feet.

Dr. J. E. Wolff, of Harvard University, has very kindly examined under the microscope a slide made from a sample

of this material collected by the Survey and has found evidence pointing to the possibility of its being composed partly of volcanic ash, though, as he suggests, further laboratory work will be required to determine the matter definitely. He describes the section as composed of rather angular small clastic grains of quartz and of fragments of triclinic feldspar, often much bent and rounded, and sometimes angular; together with deep brown homogeneous grains which are partially transparent, but completely isotropic in polarized light. The latter show no signs of cleavage or crystal structure, and look like possible fragments of a ferruginous basaltic glass. The clastic grains are separated by thin films of a green chloritic substance.

Lack of time has not yet permitted a further investigation of this subject, but should this deposit, representing, as it does, the parting between the Silurian and Carboniferous terranes, prove to be an ash bed, it will throw additional light on the series of phenomena which took place in the interval between those ages. That the deposit is not of this nature everywhere in the region, is shown by the fact that in many places, even in the neighborhood of the Meeker locality, it consists of what seems to be a common sedimentary sandstone, though in some places the grains composing it show a very remarkable globular form.

Dr. J. C. Branner, State Geologist, had already suggested, from his examinations in the field previous to the discovery of the above mentioned locality, that the parting between the Silurian and Carboniferous in northern Arkansas might contain eruptive debris, and should the case in question prove to be composed of such materials it will materially substantiate this view. Dr. J. Francis Williams,* of the Survey, had also discovered, previous to the present discovery, a somewhat similar material in the Paleozoic rocks of southwestern Arkansas.

* See report on the Igneous Rocks of Arkansas, Vol. II., of the publications of the Survey for 1890.

THE BOONE CHERT.

Name.—The name Boone has been given by the State Geologist, to the series of cherts and cherty limestones, which forms the base of the Carboniferous system in the Batesville region and elsewhere in northern Arkansas. It is taken from Boone county, where these rocks form the predominating feature of the region.

Composition of the Boone chert.—The formation consists of a series of interbedded strata of chert and limestone. The two materials differ greatly in relative amounts in different places, sometimes the whole deposit being composed almost entirely of chert, and sometimes consisting of over half limestone. In places where chert is the predominating constituent of the bed, the limestone occurs as thin strata or lenticular layers, and very often as irregularly shaped bunches or masses, varying from half an inch to several inches in diameter. Frequently the chert contains isolated crystals of calcite, at times large enough to be seen with the naked eye, and at others only visible under a microscope. In parts of the bed where limestone is the predominating feature, the chert occurs as thin strata, lenticular layers or as bunches like those of limestone just mentioned. Frequently it occurs as a finely disseminated siliceous material throughout the mass of the limestone. One of the most common phases of the chert bed in the manganese region is a central mass of more or less calcareous chert, about 100 feet in thickness, overlain and underlain by a series, 25 to 50 feet in thickness, of interbedded chert and limestone strata, the limestone becoming more and more plentiful, both above and below, until the chert layers either entirely disappear or are represented only by small irregular segregations and disseminated siliceous impurities. Frequently, however, limestone beds are found in the central part of the deposit, and sometimes acquire a thickness of a hundred feet or more. These beds usually contain numerous lenses of chert and are frequently

cut up into separate limestone beds by more or less continuous layers of chert.

The character of the limestones in this cherty deposit differs very much in different localities, and at different horizons in the series. They vary from a massive gray or blue limestone of a compact structure and more or less siliceous nature, to a highly crystalline gray variety, often strongly charged with organic matter. Between these limits are found all gradations in structure, purity and color. The bed that preserves the most uniform consistency, though of intermittent occurrence, is a cherty limestone which occurs at the very top of the deposit. This is of a white or light gray color, and is composed of small, transparent, granular crystals of calcite, having the size and general appearance of finely granulated sugar, and imbedded in a massive white, calcareous cement. It contains variable quantities of chert in the form of lenses. It has been quarried at Ward's quarry, seven miles northeast of Batesville, and at Allen's quarry, two miles north of the same town, for a building stone and as a source of lime. It takes a beautiful polish and is well adapted for structural purposes.* A similar rock in a similar position, is seen on the north side of the wagon road to Mountain View, three miles west of Batesville, where the road passes under the St. Louis, Iron Mountain and Southern Railway. This limestone is not continuous: in some places it disappears altogether and in others it reaches a thickness of over fifty feet.

Another very characteristic limestone of this series is a coarse grained, highly crystalline variety, such as is seen at Denieville, six miles northwest of Batesville. This is highly bituminous and emits a strong fetid odor on a fresh fracture. A thickness of a hundred feet of it is exposed at this point. Like the other limestones of the chert beds, it is cut up by numerous cherty lenses which frequently assume a peculiar undulating position. Similar limestones are seen along the line of the

* See the report on Marble and Other Limestones, by Mr. T. C. Hopkins, Vol. IV., annual report of the Geological Survey for 1890.

Mountain View road, from five to eight miles west of Batesville. Besides the varieties of limestone already mentioned, an earthy variety, and a hard, siliceous, semi-crystalline form frequently occur.

The chert, where seen in large deposits, is a bedded siliceous rock, generally of light gray or drab color. It is often stained yellow or brown by iron, and is sometimes black. It is very hard and brittle, has an angular to conchoidal fracture and a lustre, varying from dull to resinous. Frequently masses of a chert breccia occur, composed of fragments of chert from an eighth to a half inch in diameter and cemented in a hard, massive, siliceous matrix. Often a breccia of similar chert fragments with a black earthy manganiferous cement, as well as a chert cut up by a net-work of thin black films of manganese occur. These, however, are secondary products, the manganese having come, probably, from the underlying St. Clair limestone, and will be described more fully in chapter VIII. Iron pyrites is frequently found in the chert in the form of small disseminated crystals and, on an exposed surface, its presence is shown by rusty, brown blotches, due to its oxidation. Frequently, also, dark gray or smoky black spots occur, which gradually blend into the lighter colored part of the rock.

The nature of the chert bed has, in some places, been changed to such an extent by chemical action, that the originally massive rock has been partially converted into a fine-grained crystalline material, often containing cavities lined with larger crystals of transparent quartz. Such occurrences, however, are only local: they are seen in places in the chert bluffs of Stone county, opposite Penter's Bluff; and near Cushman and on the upper part of Polk Bayou, in Independence county.

Sandstone in the Boone chert.—A noticeable feature of the chert is the existence in it of interstratified beds of sandstone. These are from one or two to eight or ten feet in thickness, and probably, in some places, are still thicker. They are, sometimes, traceable for almost a mile, but probably represent lenticular strata in the chert. Sometimes they appear to exist simply as pockets in the chert. These sandstones are composed of coarse,

angular and rounded grains, are soft and friable, and of a gray, buff, rusty-brown, or red color. They frequently contain concretionary nodules of chert, as well as angular masses of the same material. The latter sometimes become sufficiently numerous to form a breccia with a sandstone matrix. Such breccias are seen on the land of Squire Meeks, in 14 N., 7 W., section 3; and also in 15 N., 8 W., section 25. In both places, the material is of only local occurrence. The interbedded sandstone is well seen about two miles southeast of the mouth of Lafferty Creek, in a hollow which makes up into the chert from the White River. The bed here is about eight feet thick, contains nodules and angular fragments of chert from an eighth of an inch to six inches in diameter, is of a buff color, friable and composed of coarse, angular, transparent grains. It crops out in the chert bluffs of the ravine and dips with the chert at an angle of 3° to the east and southeast. The accompanying columnar section

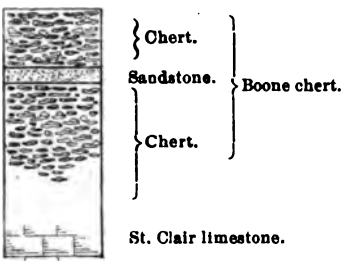


Figure 6. *Section showing the occurrence of sandstone in the Boone chert, in the White River valley.* Scale: 1 inch=25 feet.

shows its position. Similar sandstones are seen elsewhere in the neighborhood, and also between here and Cushman.

Shale in the Boone chert.—In some places in the chert there occur lenticular strata of a black, massive or slaty, bituminous shale, containing considerable quantities of shells of small *Lingulae*, as well as iron pyrites, either in crystals or in thin interbedded layers, one thirty second to one sixteenth of an inch in thickness. The bed has been dug into for coal in several places, but without finding any. The accompanying chert in such places is sometimes of the same black color as the shale. In 14 N., 5 W., section 15, the northwest quarter, the bed was opened for a

depth of twenty feet without reaching the bottom. In an old prospect pit, in township 14 N., 6 W., section 33, north part, the accompanying section was obtained, being made up partly from exposures on the hillsides, partly from the materials on the dump and partly from the statements of the owner of the property. The first member of the section represents the series of cherts and

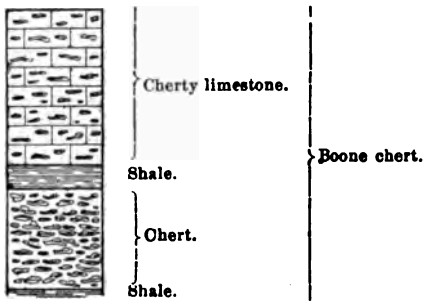


Figure 7. *Section showing the occurrence of shale in the Boone chert, in township 14 N., 6 W., section 33.* Scale: 1 inch=25 feet.

limestones that overlie the main chert bed. Considerable quantities of iron pyrites are found in all the rocks at this place. Such slate or shale beds are only of local occurrence and represent lenticular strata in the main chert formation.

Topography of the chert area.—The erosion of the chert gives rise to a very characteristic topography, forming steep hills, sometimes with slopes covered by loose chert fragments which obscure everything else, sometimes rising up almost perpendicularly in the sides of ravines 80 to 100 feet deep, in which the almost horizontal strata are clearly exposed. Still again, the chert forms the capping of the underlying limestones on high river bluffs and rises up in bold angular escarpments, projecting in rugged, turret-like forms, or receding in deep stony gullies. The chert breaks easily along the planes of bedding, and surface waters, percolating through these passages have often formed narrow cavities, giving the bluffs a peculiar loose appearance. Frequently there occur at the base of such bluffs numerous flat slabs of chert varying from four to twenty-four inches in thickness and with uneven, undulating surfaces. At its northern limits, the chert formation thins out and is finally represented only by loose piles of broken, angular chert, capping low hills or abrupt conical knobs.

Caves in the Boone chert.—Caves are very numerous in the upper and lower parts of the chert series. These appear to have been formed by the leaching out of the limestone layers and the gradual dropping in of the associated chert. Sometimes the leaching action shows itself simply in the form of a conical hollow in the side of the chert hill, and no open cavity is visible, but in other places large caverns have been formed, which consist of a series of chambers of very irregular shape, varying from 50 to 100 feet in height, and width, and connected by narrow passages. In some places streams of clear water gush from the caves; while in other places the latter serve as "sink-holes", into which streams flow, and, passing through underground channels, again appear as springs elsewhere. In most cases, the beds of limestone, which characterize the chert, can be seen on the sides of the caves, and prove clearly the origin of the latter. Stalactites and stalagmites are rare, though sometimes found in small quantities. The sides and roof are usually comparatively smooth, but the floors are covered with loose chert blocks which have fallen from above and have accumulated in great heaps. Such caverns are frequently the haunts of great numbers of bats.

Decay of the Boone chert.—The surface of the whole chert area is strewn with loose angular chert fragments, and the rocks are rarely seen in place, except where they are exposed in steep bluffs. The surface leaching of the interbedded limestone in the upper part of the formation has loosened the chert strata, and is doubtless one of the causes of this very characteristic surface. The fragments vary from one inch to two feet or more in diameter and have often collected in large quantities on the slopes of the hills. This breaking up of the chert beds, however, is not always confined to the surface. In the northern part of the region of its exposure, the chert has been undermined and let down by the leaching out of the underlying St. Clair limestone, and the whole formation has been much broken, shattered, and faulted from bottom to top. This often gives it the appearance, at first sight, of having been disturbed by lateral pressure, but the horizontal or gently sloping position of the underlying rocks precludes such a supposition, as will be shown in chapter VIII.

The chert fragments found on the surface are frequently honeycombed by small cavities an eighth of an inch to one inch in diameter and very irregular in shape. These are due to the leaching out of included masses of limestone. The real nature of the chert is never seen on an exposed surface and it is only in a freshly broken mass that the original structure of the rock becomes visible. When exposed to the process of decay, the chert undergoes two stages of decomposition: first, into a light, porous, opaque, buff-colored rock of the consistency of an ordinary pressed brick; second, into an impalpable white or brown powder, locally known as "polishing powder". This last stage of decomposition is not seen so often as the first, as the surface waters rapidly carry off the fine material as fast as it is formed. In places, however, where there are conditions for its preservation, it has collected in considerable quantities. The white powder frequently contains masses of the porous, semi-decomposed rock, the latter in turn encircling kernels of hard unaltered chert. Throughout the chert area generally, the rock has usually been converted, superficially, to a more or less porous mass, sometimes reaching ten feet or more into the rock and at other times only a fraction of an inch. This is very characteristically shown in the accompanying section, which is seen exposed about six miles northwest of Batesville.

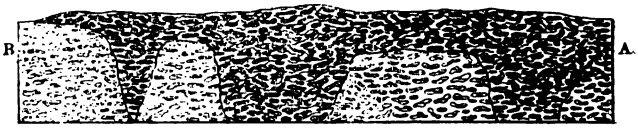


Figure 8. *Section showing the irregular decay of the Boone chert.*
A. Decomposed chert.
B. Undecomposed chert.
Horizontal and vertical scale: 1 inch=30 feet.

The decomposition is doubtless due partly, if not wholly, to the leaching out of carbonate of lime and other carbonates disseminated through the chert, either in the form of minute crystals, or as an amorphous powder. The varying amounts of these materials in different parts of the chert possibly account

for the unequal decay of the rock. The removal of the carbonates leaves a skeleton of the less soluble siliceous parts.

Microscopic examination of the Boone chert.—A microscopic examination, kindly made for the Survey by Dr. J. E. Wolff, of Harvard University, of chert specimens collected in the Batesville region, have shown them to be composed largely of chalcedonic silica, though in some cases the silica is possibly in an opaline form. They show numerous rhombohedral crystals of carbonates, many of which are doubtless calcite, as shown by chemical tests. Others have been determined by Dr. Wolff as being rhombohedral cavities filled with limonite or with black oxide of iron. The iron also, at times, occurs in shapeless bodies or impregnates the other carbonates, suggesting in some cases, as shown by Dr. Wolff, that the latter may have been originally siderite or ferruginous calcite. Flakes of muscovite mica were also found in one of the specimens examined. He describes one specimen as "composed of a mass of chalcedonic silica in little, fibrous, irregularly shaped masses which often cross each other at right angles like the structure of cloth or are arranged radially." Larger masses, arranged radially in imperfect spherulites, are interspersed. There is a large amount of opaque ferruginous material (ferruginous clay?) scattered about in small specks, and also abundant little, more or less cloudy rhombohedrons, which, from their form, suggest a carbonate.

A second specimen, he describes as containing a great number of small rhombohedrons largely filled with limonite or black oxide of iron. Small irregular bodies of the same substance occur abundantly in the specimen, and flakes of muscovite are scattered here and there through it.

A third specimen is described by Dr. Wolff as being composed of chalcedony with the same structure as the first. Cloudy bands are seen in the specimen and are made up of aggregates of little rhombohedrons with curved surfaces, evidently representing a carbonate. They are often limonitic, suggesting that they may have been originally siderite or ferruginous calcite.

A specimen of a highly calcareous part of the chert bed was

found by Dr. Wolff to be "composed principally of calcite in irregular grains and masses," cloudy by admixture with argillaceous (?) material; and with little branching areas of silica among the calcite aggregations.

The presence of the carbonate rhombohedrons in chert is not an unusual occurrence, and is simply an expression of the chemical changes which have gone on in the chert since its deposition. Similar crystals occur in many cherts elsewhere, and Mr. L. S. Griswold* has found them in the novaculite of southwestern Arkansas.

The evidence in the field, seems to point to the original deposition of the cherts as a siliceous sediment, separated at varying intervals by calcareous deposits of greater or less thickness. The deposition of the siliceous and calcareous materials seems, sometimes, to have taken place at the same time, instead of at separate intervals, thereby giving rise to the calcareous cherts and the siliceous limestones characteristic of the deposit. The theory of the origin of chert by a replacement of carbonate of lime by silica seems, at least in most parts of this region, to be untenable; on the other hand the presence of shale and sandstone strata, of pockets of sandstone and occasional grains of sand in the chert, as well as the sharp contact often seen between chert and limestone strata, would lend support to the supposition that the chert was originally a siliceous sediment, not of the coarseness of sand but in the form of a very fine siliceous clay or mud, such as is represented by the material carried down by many rivers at the present day. The presence of sand in such a deposit is probably to be accounted for by the temporary increase in speed of the waters carrying the sediments, thus bringing sand in place of the lighter materials usually carried by the quieter waters

Fossils in the Boone chert.—Fossils are frequently found in the chert and the associated limestones. When in the chert, they usually occur as siliceous casts, the carbonate of

* See Vol. III., annual report of the Geological Survey for 1890.

lime of the original remains having been leached out and hollow spaces left. In places, these cavities are so numerous as to give the rock a porous, honeycombed appearance. All the specimens collected from this deposit have been determined by Dr. H. S. Williams as belonging to the lower part of the Lower Carboniferous or Mississippian series. (See page 115.)

THE FAYETTEVILLE SHALE.

Above the Boone chert, is a series of black or gray shales with thin beds of siliceous black limestone and of sandstone. This formation has been named the Fayetteville shale by the State Geologist, on account of its extensive development near the town of that name.* Sometimes in the Batesville region it consists largely of dark gray or black shale, and at other times it contains, especially at its base, beds of highly fossiliferous black limestone. The whole series is highly siliceous, and the limestone and calcareous shales, when exposed to the leaching action of surface waters, give rise to a very porous, light, siliceous skeleton. Associated with the shales are often found iron pyrites, partly oxidized nodules of carbonate of iron and calcareous concretions, the latter often containing fossil remains. The thickness of the Fayetteville shale is exceedingly variable: sometimes the deposit is thin and the overlying Batesville sandstone comes close to the Boone chert; elsewhere it has an aggregate thickness of probably over 200 feet. Definite estimates of the thickness of this formation greater than 190 feet have, however, not, as yet, been made in the country surrounding the manganese region, though it doubtless is, in some places, considerably thicker than that.

In the Batesville region, the Fayetteville shale is well developed in the neighborhood of Moorefield, Sulphur Rock, and thence south to the White River, and north to beyond Sharp's Cross Roads. To the west, between Batesville and Penter's

* Fayetteville is in Washington county, in the northwestern part of Arkansas, and is not shown on the map accompanying this volume. See Vol. IV., annual report of the Geological Survey, 1888.

Bluff, it and the associated limestones are seen at intervals between the areas of overlying sandstones and the underlying chert. But, in this region, it covers a much smaller area than to the east, and its outcrop is rarely over a few hundred yards wide.* Its geologic position is shown in the columnar section on page 113.

The Fayetteville shale is so intimately associated with the Batesville sandstone in its areal distribution, that, in the map accompanying this volume, one color is employed for both formations.

THE BATESVILLE SANDSTONE.

Overlying the Fayetteville shale, is a sandstone formation with lenticular beds of gray, black or brown shale. This formation lies on both sides of the White River, reaching to the area of the Fayetteville shale and the chert hills on the north, and, on the south, disappearing under the overlying rocks at the foot of the Boston Mountains. It is well developed at the town of Batesville and has been named, by the State Geologist, the Batesville sandstone. It consists of a brown or buff colored, fine grained sandstone, generally soft, though sometimes hard. It splits easily along the lines of bedding, in slabs varying from a few inches to three or four feet in thickness, and is extensively worked for structural purposes at Bartlett's quarry, in Batesville. The shales in the sandstone occur as lenticular deposits, often ending very abruptly, though sometimes traceable for several miles. They and the sandstones appear, in many places, to be mutually replaceable. The thickness of the Batesville sandstone is very changeable, varying from twenty or thirty feet to almost two hundred feet. One mile east of the town of Batesville, on the bluffs of Blue Creek, it shows a thickness of 170 feet, and, as it is still at the foot of the bluffs, it is probably thicker.

Going east from Batesville, the old "wire road" follows,

* As already stated on pages 110-111, a line of weakness, marked by occasional faults, exists in many places west of Batesville, about on the outcrop of this shale, and it seems possible that the small exposures, in some places, may be due to this faulting.

for four miles, the summit of a high ridge of Batesville sandstone, some 200 feet above the White River, and then descends to the level of the underlying shales.

THE FORMATIONS COMPOSING THE BOSTON MOUNTAINS.

Boston group.—The Boston Mountains, as already stated, begin on the east at the western edge of the lowlands of Newport and Oil Trough Bottom, and bear thence northwest up the south side of the White River. They rise from 500 to 600 feet above the river and end on the north in an abrupt escarpment. To the south they dip off gently in a broad, sandy, heavily timbered highland. They form the southern border of the White River basin, and lie to the south of the manganese area of the Batesville region. In their eastern part, these mountains are composed entirely of Lower Carboniferous rocks capped by the Millstone grit, but in the northwest part of the state, they become much higher and are more deeply cut by steep ravines, in the sides of which the underlying Silurian rocks are seen. In the north face of the mountains, in Independence and eastern Stone counties, the formations are often well exposed. The Batesville sandstone disappears under the mountains at their base, and above it is a series of shales, limestones and sandstones, representing the Boston group. Their sequence, as seen in the region south and southwest of Jamestown, is shown in the columnar section, on page 113. The shale immediately overlying the Batesville sandstone forms, in many places, a prominent feature of the country. It has been named the Marshall shale by the State Geologist, on account of its well developed condition in the neighborhood of the town of that name in Searcy county.

Millstone grit.— The Millstone grit overlies the rocks of the Boston group of the Lower Carboniferous and represents the uppermost formation of the Carboniferous system in this region. It varies considerably in thickness and reaches a maximum, so far as observed, of over 400 feet. Possibly further investigation will show it to have, locally, a still greater development.

The formation was determined by Owen* as early as 1858, as the Millstone grit, and since then later investigations have still further strengthened his correlation. The rock is of a buff or brown color, varying from soft to hard and compact. It is composed of sand grains of various sizes and frequently contains well rounded, white, siliceous pebbles, a sixteenth of an inch to a half inch in diameter. These either occur as isolated pebbles imbedded in the sandstone, or form the larger part of a conglomerate with a sandy matrix. Such beds, however, do not form any prominent feature of the sandstone, being of a very limited thickness and lateral extent. Sometimes the sandstone assumes a shaly or fissile structure. Frequently it is highly stained with iron, giving it a rusty appearance, and, in some places, it contains small seams of iron ore (limonite).

The Millstone grit caps the highest parts of the Boston Mountains and is the most prominent feature of the region. It forms an almost continuous escarpment on the summit of the northern face of the mountains, at times receding where creeks have cut down into it, and at others protruding in high bluffs, such as are seen at Dean's Mountain, five miles west of Batesville, and elsewhere. Ascending the steep slopes of the Boston Mountains to the southwest of Jamestown, a sandy highland is reached, underlain by this bed and heavily covered with pine, oak and other timber. This forms the southern boundary of Independence county and extends into Cleburne county on the west, and to the head of Oil Trough Bottom on the east. At the latter place, the mountains end abruptly, in the same way as at Jamestown, showing a section capped by four hundred feet of sandstone and underlain by shales and black limestones.

THE PLEISTOCENE AND RECENT AREA.

The low country, already mentioned as bounding the mountainous area on the east, has not been studied by the writer and will, therefore, be simply mentioned here. It is covered, at least

* A Geological Reconnoissance of the Northern Counties of Arkansas, D. D. Owen, State Geologist, 1858, p. 137.

superficially, by Pleistocene or later sediments, in the form of clay, sand and gravel, and represents the western part of the Mississippi bottom. Between this area and the Mississippi, however, are found Tertiary strata in Crowley's Ridge, which have been treated in detail by Professor R. E. Call.* Below Newport, Tertiary strata occur at several places along the line of the St. Louis, Iron Mountain and Southern Railway and near the base of the Paleozoic escarpment. Hence it is more than probable that the area in question is also underlain by Tertiary beds and that it represents a part of the northern extension of the Mississippi embayment which, in Tertiary times, extended up the river into this region. It is very probable that a further investigation of this region will prove the local existence of Tertiary beds on the surface, but in the absence of evidence to this effect, and in view of the fact that the predominating surface materials are Post-Tertiary, the area has been provisionally marked, on the map of the Batesville region, as Pleistocene and Recent.

The gravel varies in size from pebbles a fraction of an inch to over twelve inches in diameter. It is more or less rounded and is composed mostly of chert, with smaller quantities of sandstone and quartzite. It is frequently associated with sand or clay, or both, either as interbedded strata or as an intimate mixture.

The gravel is especially well represented on the Paleozoic escarpment at the junction of the lowlands and the highlands. It probably, in some places, reaches a depth of over 75 feet. It frequently conceals the underlying Paleozoic rocks over areas of several square miles, but occasionally a deep ravine has cut down to its base, or a rocky knob protrudes through it, proving the existence of rocks similar to those found in the less heavily covered country to the west. The gravel continues to occur as a heavy covering for from one to five or six miles back from the escarpment. Beyond this, it forms a less prominent feature of the country and, though never entirely

* See Vol. II., annual report Geological Survey for 1889.

absent over any considerable area, it is much thinner and occurs in isolated patches. In this region it usually occurs on the tops of the hills, sometimes as scattered pebbles and at other times in beds twenty and thirty feet thick. Some of these hills rise 400 to 500 feet above the level of the White River. In the neighborhood of Cushman, and thence east to Dota Creek and north to Barren Fork, it is found on many of the highest hills. Most of the hills of this region are capped with chert, the characteristic surface of which is a mass of loose angular cherty fragments resulting from the weathering of the underlying bed. These have become mixed with waterworn material in varying proportions, and, as a result, rounded pebbles are often found at a depth of ten feet or more in loose angular chert.

CHAPTER VII.

THE BATESVILLE REGION OF ARKANSAS.—*Continued.*

MINERALOGICAL FORMS OF THE MANGANESE ORES.

General statement.—All the manganese ores of the Batesville region are oxides of manganese in various mineralogical forms. There are two principal varieties of these minerals: one massive and representing the mineral psilomelane; the other crystalline and possibly representing the mineral braunite. Between the massive and the crystalline forms there are all gradations in degree of admixture; the one blends into the other, and it is often impossible to draw a sharp line of demarcation. The massive variety almost always contains some of the crystalline variety, which, at first, exists only as minute crystalline specks scattered through the massive matrix, but becomes more and more plentiful, until the whole material merges into a coarsely crystalline aggregate.

Besides these two principal forms of manganese oxides, there are also found smaller quantities of pyrolusite and of wad. Possibly further investigation may show the existence of still other varieties of the manganese oxides, though the analyses so far made, have not proved the presence of either manganite or hausmannite; nor has any evidence of the existence of polianite yet been found in the region in question.

As early as 1858, Dr. Wm. Elderhorst, chemist of the Geological Survey of Arkansas under Dr. David Dale Owen, gave analyses of manganese ores* from Independence and Izard counties, and described three samples of psilomelane, one of wad, and one which he considered probably braunite. These are further

* First Report of a Geological Reconnoisance of the Northern Counties of Arkansas, 1857-1858, pp. 161-169.

referred to in the following pages. Below are given descriptions and analyses of typical samples of the different oxides of manganese collected in the Batesville region by the present Survey.

Psilomelane.—Specimen from Cave Creek, nine miles north of Batesville, Independence county. This is a dark, steel-blue or black, massive mineral; opaque; lustre submetallic; streak brown; fracture smooth, conchoidal; hardness 6. Its specific gravity is 3.72. The mineral occurs in irregular masses, sometimes reniform and botryoidal, sometimes porous and with apparently no physical structure.

With fluxes it gives manganese reactions; in hydrochloric acid it dissolves with the evolution of chlorine.

An analysis made by Dr. R. N. Brackett, Chemist of the Survey, of this material dried at 110°-115° Centigrade gave the following results:

Analysis of psilomelane from the Batesville region.

Manganese protoxide (MnO)	77.65
Oxygen (O)	14.56
Ferric oxide (Fe_2O_3)	0.90
Alumina (Al_2O_3)	0.80
Lime (CaO)	1.81
Baryta (BaO)	0.21
Magnesia (MgO)	very slight trace.
Potash (K_2O)	1.99
Soda (Na_2O)	0.97
Phosphoric acid (P_2O_5)	0.67
Silica (SiO_2)	0.83
	100.59

The analysis and the physical properties of the mineral show it to be a psilomelane. Rammelsberg* describes psilomelane under two different headings, those varieties high in baryta being classed as baryta-psilomelane, and those low in baryta and high in potash being classed as potash-psilomelane. The specimen in question, as compared with other varieties of psilomelane, is low in baryta and does not contain as large a

* Handbuch der Mineralchemie, second edition, 1875, pp. 189-192.

percentage of potash as some, but can be included under the head of potash-psilomelane. Its specific gravity (3.72) is low, but is within the limits given by Prof. J. D. Dana * (3.7-4.7). The mineral contains numerous small cavities which, possibly, may partly account for the low specific gravity obtained. The specific gravity was determined, however, with a powdered sample, so as to avoid this source of error as far as possible.

The following two analyses of potash-psilomelane, the first (1) from Ilmenau, Germany, † and the second (2) from Schneeberg, ‡ Germany, are given for comparison with the Arkansas specimen.

Analyses of German psilomelane.

	Psilomelane from Ilmenau.	Psilomelane from Schneeberg.
Manganese protoxide (MnO)	77.23	80.27
Oxygen (O)	15.82	14.10
Copper oxide (CuO)	0.40	.....
Lime (CaO)	0.91	1.05
Baryta (BaO)	0.12	.....
Magnesia (MgO)	.....	.....
Potash (K_2O)	5.29	4.35
Water (H_2O)	.....	0.23
	99.77	100.00

The following descriptions and analyses of specimens of psilomelane from the Batesville region are given by Wm. Elderhorst, Chemist of the former Geological Survey of Arkansas under D. D. Owen: ||

"No. 20. Psilomelane, from the main manganese mine, two miles above west fork of Lafferty Creek, Independence county:

"Massive; lustre submetallic; color between dark steel-gray and iron-black; hardness, 5.5; fracture subcrystalline, hackly,

* System of Mineralogy, fifth edition, 1883, p. 180.

† Analyzed by Clausbruch, quoted by C. F. Rammelsberg, Handbuch der Mineralchemie, second edition, 1875, p. 190.

‡ Analyzed by Schultz, quoted by C. F. Rammelsberg, Ibid., p. 190.

|| First Report of a Geological Reconnoissance of the Northern Counties of Arkansas, D. D. Owen, State Geologist, 1858, pp. 161-163.

somewhat resembling the fracture of cast iron; brittle; strikes fire with steel; powder reddish-brown.

"Before the blowpipe, infusible alone; on charcoal in reduction flame becomes reddish-brown; in a matrass, yields water; with fluxes, gives the manganese reactions. Dissolves in hydrochloric acid with evolution of chlorine, leaving a small residue of silica. * * *"

"The air-dried mineral lost 0.53 per cent of moisture at 250 degrees F."

The composition of the specimen dried at 250° Fahrenheit is given as follows:

Analysis of psilomelane from the Batesville region.

Manganese protoxide (MnO)	84.995
Oxygen (O)	10.483
Lime (CaO)	trace
Baryta (BaO)	0.512
Water (H_2O)	1.820
Silica (SiO_2)	2.845
	100.655

"No. 21. Psilomelane, from same locality as No. 20.

"Massive; close-textured; color bluish steel-gray; hardness 5.5; fracture splintery and subconchoidal; brittle; strikes fire with steel; powder reddish-brown.

"Before the blowpipe, and to reagents, behaves like the preceding.

"The air-dried mineral lost 1.02 per cent of moisture at 250 deg. F."

The composition of the specimen dried at 250° Fahrenheit is given as follows:

Analysis of psilomelane from the Batesville region.

Manganese protoxide (MnO)	82.448
Oxygen (O)	10.062
Lime (CaO)	1.178
Baryta (BaO)	0.282
Magnesia (MgO)	trace
Water (H_2O)	0.611
Silica (SiO_2)	5.329
	99.850

Braunite.—Specimen from the Sullivan Creek fork of Polk Bayou, ten miles north of Batesville, Independence county. This is a dark, iron-gray or black mineral, forming a coarsely crystalline aggregate with a marked cleavage, the crystallographic position of the cleavage being uncertain; lustre submetallic; streak dark chocolate-brown; hardness 5 to 5.5. Its specific gravity, as determined by the Chemist of the Survey, is 4.50.

With fluxes it gives manganese reactions; it dissolves in hydrochloric acid with the evolution of chlorine.

The following analysis was made mostly by Dr. R. N. Brackett and partly by Prof. W. A. Noyes. It shows the composition of the mineral dried at 110°–115° Centigrade.

Analysis of braunite from the Batesville region.

	Per cent.	Ratio.	
Manganese protoxide (MnO)...	87.47	1.232	2.05
Oxygen (O).....	9.62	0.601	1.00
Ferric oxide (Fe_2O_3).....	0.44		
Alumina (Al_2O_3).....	0.11		
Lime (CaO).....	0.34		
Baryta (BaO).....	0.48		
Magnesia (MgO).....	trace		
Potash (K_2O).....	0.10		
Soda (Na_2O).....	0.05		
Phosphoric acid (P_2O_5).....	0.25		
Silica (SiO_2).....	0.18		
	99.04		

It will be observed that the ratio of MnO to O is almost exactly as 2 : 1, which is the theoretical ratio of manganese sesquioxide (Mn_2O_3). It will also be noticed that the analysis shows less than 2 per cent of ingredients other than MnO and O, and the mineral is therefore a very pure Mn_2O_3. Though the mineral occurs as a compact crystalline aggregate and not as isolated crystals, it seems, judging from its general appearance and its physical characteristics, to be homogeneous.* In some other specimens of a similar material

* The original specimen contained inclusions of a massive or semi-crystalline oxide of manganese, but the sample analyzed was carefully separated from this and was composed only of the coarsely crystalline parts.

there were found some very small crystals, apparently tetragonal pyramids, suggesting, from their general form, that they might be braunite. Hausmannite crystallizes in the same system, but the above analysis does not show any close relation to the composition of that mineral. The analysis shows a mineral resembling in all respects a braunite without silica, and the physical features of the specimen, as far as they can be distinguished, are also those of braunite.

Wm. Elderhorst,* in 1858, gave an analysis of a specimen of manganese oxide from the Batesville region which he considered probably braunite. It contained 9.968 per cent of silica, and came from the same region as the specimen in question, in which practically no silica was found (0.18 per cent). It was massive, however, so that the chemical relation of the silica to the oxide of manganese was uncertain. Elderhorst describes the specimen and discusses the analysis as follows:

"No. 23. Braunite (?), from Poke Bayou, Marion county.†

"Massive; texture finely granular; lustre submetallic; color dark steel-gray; hardness 5.5; strikes fire with steel; powder grayish-black; much more easily reduced to powder than the two preceding minerals; weathered surface shows brown spots of hydrate of peroxide of iron.

"Before the blowpipe, infusible; on charcoal in reduction flame, becomes pale reddish-gray at the point of contact with the charcoal; in a matrass, yields a little water; with fluxes, gives the manganese reactions.

"Dissolves in hydrochloric acid with evolution of chlorine, leaving a residue of silica. Composition dried at 220 deg. F.:

Protoxide of manganese (MnO)	75.886
Free oxygen (O)	7.979
Peroxide of iron (Fe_2O_3)	3.523
Oxide of cobalt (CoO)	trace
Lime (CaO)	1.833
Magnesia (MgO)	0.192
Water (H_2O)	1.295
Silica (SiO_2)	9.968
	100.176

* First Report of a Geological Reconnoissance of the Northern Counties of Arkansas, by D. D. Owen, 1858, pp. 164-165 and 169.

† This reference to Marion county is doubtless a mistake for Independence county, as Dr. Elderhorst refers in his report to having received the specimen in Batesville, Independence county. Besides, Poke Bayou, now spelled Polk Bayou, is in Independence county and not in Marion.

"The air-dried mineral lost 0.1 per cent of moisture at 220 deg. F. * * *

"Proceeding in the same manner with the analysis of No. 28, that is, rejecting silicic acid and peroxide of iron, and calculating the remainder for 100, we have:

Protoxide of manganese (MnO)	86.96
Oxygen (O)	9.20
Lime (CaO)	2.12
Magnesia (MgO)	0.22
Water (H_2O)	1.50
	100.00

"86.96 parts of protoxide of manganese consist of 67.41 of manganese and 19.55 of oxygen; hence we have, in toto, 67.41 manganese to 28.75 oxygen, corresponding to the ratio:

69.68Mn : 29.72 O;

The compound Mn_2O_3 requires.....69.68Mn : 30.42 O;

so that the mineral may be considered as a sesquioxide of manganese, or braunite, under the supposition that we are justified in rejecting lime, magnesia, and water as adventitious. But if these bases have to be taken into consideration, and the free oxygen is united with a portion of the protoxide of manganese to the formation of peroxide, we have:

Peroxide of manganese (MnO_2)	50.10 contains O		18.40
Protoxide of manganese (MnO)	46.06 contains O	10.36	12.37
Lime (CaO)	2.12 contains O	0.60	
Magnesia (MgO)	0.22 contains O	0.08	
Water (H_2O)	1.50 contains O	1.33	

"Here the oxygen-ratio of RO : MnO_2 is nearly as 4 : 6, which would lead to the formula

4 (MnO. CaO. MgO. HO). 3 MnO_2."

It is evident from Elderhorst's discussion of the mineral, that he considered the silica in it to be an accidental ingredient, but, at that time, the nature of the siliceous braunites was not so well understood as at present.

The composition of pure braunite has for a long time been

a matter of considerable discussion and, in some respects, still continues to be an uncertain question. The mineral is stated by most authorities to contain silica in chemical combination, and various formulas are given to explain the relation of the silica and the manganese. Some authors, however, describe braunite as a sesquioxide of manganese frequently containing silica as a mechanical admixture, while others think it is a combination of one molecule of protoxide and one of peroxide of manganese.

Turner* obtained the formula Mn_2O_3 for a specimen of the mineral braunite from Elgersburg, Germany. He noted a siliceous residue on dissolving the mineral, but referred to it simply as a trace. On the other hand, the later investigations of Rammelsberg,† Dr. Penfield‡ and others have shown certain specimens of braunite to contain from 7.4 to over 8 per cent of silica in chemical combination. Rammelsberg found 7.4 to 8.6 per cent of silica in pure crystals of braunite from the same locality (Elgersburg) as the sample already referred to, in which Turner found no silica.

Rammelsberg § originally considered braunite to be a combination of sesquioxide of manganese and the silicate of the protoxide of manganese, having the formula $3\ Mn_2O_3 + MnSiO_3$. In later investigations, however, he found that, by heating the mineral with nitric acid, a greater percentage of the protoxide was obtained than would be afforded by the silicate in the above formula; also, that the amount he obtained approached that which would be given if the sesquioxide (Mn_2O_3) in the formula were considered to be composed of MnO and MnO_2. Therefore he proposed ‖ the following formula:

$$MnO + \begin{cases} MnO_2 \\ SiO_2 \end{cases}$$

J. D. Dana, on the other hand, though he considers the

* Trans. Roy. Soc. Edinburgh, Vol. XI.

† Handbuch der Mineralchemie, second edition, 1875, pp. 160-161.

‡ Unpublished results, see page 153 of this report.

§ Handbuch der Mineralchemie, second edition, 1875, page 160.

‖ Handbuch der Mineralchemie, 1875; Supplement to second edition, 1886, page 52.

silica in braunite to be combined with manganese, gives a different formula: he calls attention to the close relation of the crystallization of the mineral to that of rutile, and shows that this relation is brought out in the formula 2 ($2\,MnO, MnO_2$)+ MnO_2,SiO_2, which represents the mineral "as corresponding to 2 of hausmannite and 2 of a silicate analogous to zircon, with which silicate also it is isomorphous."*

Tschermak † gives the formula of braunite as the simple sesquioxide (Mn_2O_3). Hermann‡ distinguishes between braunite with silica and braunite without silica: in the case of the latter, he rejects the formula Mn_2O_3 and substitutes $MnO+MnO_2$, a suggestion that is also accepted by Gustav Rose as explaining why the mineral was not isomorphous with hematite (Fe_2O_3). He explains the occurrence of baryta and silica in some varities of braunite, by supposing that the baryta combined with MnO, and the silica with MnO_2. He proposes, therefore, to separate the braunite containing no silica from the braunite containing silica, by confining the latter to the name Marceline, a name already given to a siliceous variety of braunite from St. Marcel, in Piedmont.

Bauer|| describes braunite as an isomorphous mixture of MnO,MnO_2 and MnO,SiO_2 in which part of the MnO is replaced by BaO.

The analyses by Rammelsberg and by Turner of the Elgersburgs pecimens, and those of the Arkansas specimens are summarized in the accompanying table. It will be seen that while one sample from Elgersburg contains 8.63 per cent of silica, the other shows no silica; and, in a similar manner, while one sample from Arkansas shows 9.968 per cent of silica, the other shows only 0.18 per cent. Hence it would appear that there may exist two forms of braunite, one containing silica in chemical com-

* System of Mineralogy, fifth edition, 1883, p. 133.

† Gustav Tschermak, Lehrbuch der Mineralogie, second edition, 1885, p. 397.

‡ Cited by Naumann-Zirkel, Elemente der Mineralogie, 1885, p. 384.

|| Max Bauer, Lehrbuch der Mineralogie, 1886, pp. 317-318.

bination and with a formula differently written by various authorities; the other containing no silica and representing a simple sesquioxide of manganese (Mn_2O_3). The exact chemical structure and relations of the two materials, however, must be left for future analyses to determine.*

Analyses of German and Arkansas braunite.

CONSTITUENTS.	ELGERSBURG BRAUNITE.		ARKANSAS BRAUNITE.	
	Analyzed by Rammelsberg.	Analyzed by Turner.	Analyzed by Elderhorst.	Analyzed by Brackett and Noyes.
Manganese protoxide (MnO)	80.94	86.95	75.886	87.47
Oxygen (O)	8.06	9.85	7.979	9.62
Ferric oxide (Fe_2O_3)	.....	.....	8.523	0.44
Alumina (Al_2O_3)	.....	.....	.....	0.11
Cobalt oxide (CoO)	.....	.....	trace	.....
Lime (CaO)	0.91	.....	1.333	0.34
Baryta (BaO)	0.44	2.25	.....	0.48
Magnesia (MgO)	.....	.....	0.192	trace
Potash (K_2O)	.....	.....	.....	0.10
Soda (Na_2O)	.....	.....	.....	0.05
Water (H_2O)	1.00	0.95	1.295	.....
Phosphoric acid (P_2O_5)	.....	.....	.....	0.25
Silica (SiO_2)	8.63	.....	9.968	0.18
Total	100.00	100.00	100.176	99.04

* After the manuscript of the present report had gone to press, the following analyses of braunite from Ilmenau, Thuringer Wald, heretofore unpublished, were obtained from Dr. S. L. Penfield, of Yale College, who has kindly consented to their being published here. They were made by him of carefully selected crystals (Yale College Collection No. 2111) of a specific gravity 4.818. They show a typical case of pure braunite containing 8.15-8.28 per cent of silica.

Manganese protoxide (MnO)	80.90	81.09
Oxygen (O)	8.07	7.90
Ferric oxide (Fe_2O_3)	0.31	0.31
Lime (CaO)	0.28	0.12
Soda (Na_2O)	0.34	0.28
Water (H_2O)	0.35	0.35
Silica (SiO_2)	8.15	8.28
	98.40	98.33

(3) *Pyrolusite.*—Besides the varieties of manganese oxides already described, a crystalline pyrolusite sometimes occurs in the Batesville manganese region. It is, however, in much smaller quantities than the ores already mentioned, and exists in thin layers and irregular masses associated with them. Sometimes it fills cavities and cracks in the ore-bearing clay, appearing to be, possibly, a secondary product, from the other ores. It is a black to iron-gray mineral; opaque; lustre submetallic; streak black; hardness 2. It is sometimes easily crumbled in the fingers. It usually occurs as a finely granular, crystalline aggregate.

This ore is found in only a few places, and does not exist in quantities large enough to warrant its separation from the other ores.

(4) *Wad.*—The variety of wad known as bog manganese sometimes occurs in the Batesville region. It is usually in a black, earthy form, frequently showing glossy slickensides, and having a hardness of from 1 to 3. It is associated with more or less iron, silica, alumina, and water, the last sometimes amounting to from 10 to 15 per cent.

PHYSICAL FORMS OF THE MANGANESE ORES.

The different mineralogical forms of manganese ores in the Batesville region exhibit themselves in various physical shapes. They usually occur as loose lumps, varying in size from almost microscopic grains to masses weighing several tons. At times, however, more or less solid bodies of ore, containing several hundred tons, occur. Sometimes the separate masses have a distinctly concretionary form, and at other times they are simply irregularly shaped bodies, showing no structure whatever. For the sake of convenience in description, the different physical forms of the ores are here enumerated. They occur either together or separately.

(1) A shapeless mass of crystalline or non-crystalline ore, containing numerous irregular cavities from a sixteenth of an inch to one inch in diameter. These cavities are usually lined or filled with an impalpable clay of varied colors, black, chocolate, brown, red, yellow, or buff. Sometimes the cavities are filled

with calcite instead of clay. It is probable that all the cavities were once filled in this way, but have since been acted on by surface water, the calcite dissolved and a residue of clay left.

This variety of ore is the most common form in the manganese region.

(2) Massive or semi-crystalline ore, showing a slight tendency towards a concretionary structure, and often containing lenticular cracks, either empty or containing black, chocolate-brown, red, yellow, or buff clay. These cavities resemble the shrinkage cracks seen in nodules of clay ironstone. This variety of ore is of common occurrence, but not so generally distributed as the last.

(3) Massive ore showing a concretionary structure. The concretions are generally small, varying from the size of a mustard seed to two or three inches in diameter. The smaller ones often approach a globular form, but the larger are usually lenticular and resemble large buttons, being locally known as "button ore." They often contain cracks similar to those in the last variety of ore mentioned. The smaller concretions occur in several places on Polk Bayou; the larger at the Cason property, the Pitman place, and elsewhere. (See chapters IX. and X.) These concretionary varieties of ore are rarer than the others mentioned above.

(4) Loose nodules of an irregular shape from one inch to twelve inches in diameter, with a smooth, dull brown surface and a coarsely crystalline interior. These masses are usually solid throughout, very heavy, and show no internal evidences of concretionary structure. If any once existed it has been destroyed by the crystallization of the nodules. This variety is rare: it occurs in the Coon Creek region, in places on West Lafferty Creek, and elsewhere in smaller quantities.

(5) Shapeless masses of a soft, dull, earthy, porous ore, often containing hard spots of massive, steel-gray ore. This form occurs in many places in the manganese region.

(6) A massive, hard, black ore in stalacitic forms. This variety is rare.

(7) A black, or dark chocolate-brown manganiferous

clay, sometimes containing wad, or bog manganese. This is too low grade to be used as an ore, but, as it sometimes contains from ten to twenty per cent of manganese, it is classified here. It has been shipped for a coloring material for dark brown bricks and for other purposes. (See Brooks mine, chapter IX.) It is often found enclosing the different varieties of ore mentioned above. In most cases it doubtless represents a residual clay derived from a limestone which once contained manganese in a finely divided state, but which has since been decomposed. It has sometimes been solidified into a soft, earthy mass, with slickensides showing bright, glossy surfaces. It is often locally mistaken for plumbago. In many places it forms the cement of a chert breccia.

In conclusion it may be said that the mammillary, botryoidal, and kidney-shaped forms in the ore are much more rarely seen in the Batesville region than in the Virginia and Georgia manganese regions. In the last two regions they are often the characteristic forms, while the ore in the Batesville region tends more to retain the original condition which it had when it existed as lenticular layers in the St. Clair limestone; and the masses now found in the residual clay, though sometimes, as at the Cason place and elsewhere, of a distinctly concretionary or nodular form, are very often simply fragments of the larger bodies.

Miners' names of the ores.—For the sake of reference, the names commonly used by the miners to designate the different physical forms of manganese ores in the Batesville region are given as follows:

(1) "Lump ore." This means masses of ore large enough to pick out of the enclosing clay without the assistance of the washer.

(2) "Wash dirt." This means clay containing numerous fragments or nodules of ore too small to pay for hand-picking, and therefore sorted by means of a washer.

(3) "Shot ore." This means a variety of small fragments or nodules of ore the size of mustard seed, or a little larger.

(4) "Button ore." This means the button-shaped concretions already described on page 155.

COMMERCIAL VALUE OF THE MANGANESE ORES.

The manganese ores of the Batesville region are used altogether for the manufacture of spiegeleisen and ferro-manganese, which is by far the most important use to which manganese ores are put. The Batesville ores are better suited for this purpose than for many of the chemical uses of manganese described in chapter III.

That a manganese ore may be of value for use in the manufacture of spiegeleisen and ferro-manganese depends largely on the relative amounts of three of its constituents: first, on its being sufficiently rich in manganese; second, on its containing a sufficiently low percentage of silica; third, on its containing a sufficiently low percentage of phosphorus. An ore containing a large percentage of manganese may be rendered unmarketable by containing too much silica or phosphorus, or both; and conversely, an ore low in manganese can often be used to great advantage when it contains only small amounts of these impurities.

In a good ore, the silica should not amount to over 12 per cent at the most, and the phosphorus should not be over 0.2 to 0.25 per cent. Even as much as 0.2 per cent of phosphorus is high, and a first-class ore should contain less. Ores containing more than these proportions of silica and phosphorus can sometimes be sold for certain purposes, especially if they contain a large percentage of manganese, but they bring a lower price than the purer ores.

An ore containing less than 40 per cent of manganese is considered low grade, and, unless mined very cheaply and in large quantities, cannot be worked at a profit. In some cases, where the ore contains even less than 30 per cent of manganese but is associated with a large proportion of iron, it has a considerable commercial value as a manganiferous iron

ore, but such materials are rarely found in the Batesville region. There is almost always a little iron in the Batesville ore, but it is only in a few localities that it runs over 7 or 8 per cent, and in many places it is less than 3 per cent. In rarer cases, however, the ore contains over 20 per cent of iron.

The better classes of Batesville ores are high in manganese and frequently contain, in car-load lots, over 50 per cent of that ingredient. Some shipments have contained over 55 per cent and a few as high as from 57 to 58 per cent. Any shipments that contain over 50 per cent of metallic manganese, however, are considered first class ores.* The low grade ores frequently run from 40 per cent down, in some cases, to less than 25 per cent of metallic manganese, but large quantities of ore are shipped which contain over 50 per cent. This amount, as compared with manganese ores mined elsewhere in the United States, is very high. A part of the Canadian ore and part of the Virginia ore contain more, but these grades are in small quantities in those regions and are used for chemical purposes. It may be safely said, that of the ores used in the manufacture of spiegeleisen and ferro-manganese, the better grades of those from the Batesville region are equal, in their contents of manganese, to any others at present mined in the United States. The accompanying table of analyses, which has been kindly furnished the Survey by Mr H. M. Curry, of the firm of Carnegie Brothers and Company, represents the composition of

* In all these statements as to the quality of the Batesville ores, conclusions are drawn altogether from analyses of car-load shipments of ore, such as are given on pages 159 and 162-165. This is the surest way to arrive at a just estimate of the commercial value of the ore, since, with analyses of hand samples, there is always an uncertainty whether or not they represent the average of the ore as it would be shipped in bulk. The analyses of car-load shipments, on the other hand, are made from samples carefully taken from ore in large quantities and in the condition in which it is used. Consequently such analyses have by far the greater practical value; and as many of them as it is thought necessary to give, are compiled in the tables on pages 162-165. They represent analyses of quantities varying from one to seven car-loads, or, in other words, of quantities varying from about fifteen to a hundred tons.

Analyses of car-load or cargo shipments of manganese ores from different regions.

GRADE.	LOCALITY.	Manganese.	Iron	Silica	Phosphorus.	Moisture in sample as taken.
HIGH GRADE.	Chili	50.370	2.820	8.950	0.014	0.370
	Chili	53.581	0.660	6.680	0.022	0.350
	Cuba	49.015	1.650	8.400	0.069	6.000
	Cuba	50.644	2.740	7.760	not made	4.000
	Nova Scotia	47.174	1.980	7.800	0.012	2.500
	Crimora, Virginia	49.163	1.750	9.800	not made	6.000
	Crimora, Virginia	48.580	1.985	10.200	0.108	3.000
	Crimora, Virginia	50.541	1.957	10.120	not made	3.000
	Crimora, Virginia	48.162	4.568	10.300	0.095	3.000
	Arkansas	52.721	3.857	2.440	0.198	4.000
	Arkansas	50.142	3.505	2.950	0.165	3.000
	Arkansas	53.023	1.907	1.700	0.352	3.000
MEDIUM GRADE.	Georgia	41.248	9.100	14.400	0.109	2.000
	Georgia	41.630	1.990	10.820	0.050	4.000
	Georgia	42.856	10.491	7.300	0.139	6.000
	Georgia	44.308	4.595	10.950	0.156	6.000
	Virginia	43.379	9.633	9.750	0.068	4.000
	Virginia	43.612	6.650	10.480	0.221	1.500
	Virginia	42.953	14 850	3.600	0.184	6.000
	South Carolina	45.018	2.750	8.100	0.085	9.000
LOW GRADE.	Virginia	37.693	12.368	10.600	0.153	9.000
	Virginia	28.311	27.830	4.460	0.067	4.000
	Virginia	35.362	20.950	6.250	0.780	5.000
	Virginia	36.028	8.703	16.380	0.113	7.000
	Virginia	33.599	16.588	14.750	0.095	8.000
	Georgia	34.157	13.590	12.900	0.167	8.000
	Georgia	36.179	7.078	16.400	0.053	1.000
	Georgia	39.893	10.210	12.720	0.106	6.000
	Vermont	20.369	31.648	12.770	0.125	5.000
	Vermont	19.706	29.268	14.000	0.145	8.000

average car-load or cargo shipments of manganese ores from Arkansas, Georgia, Virginia, South Carolina, Vermont, Nova Scotia, Cuba, and Chili. The analyses are arranged under three different headings: high grade, medium grade, and low grade. It will be observed that the average contents of manganese in the Arkansas ores* is greater than in any of the others, except the Chilian which are practically the same.

Very few of the better grades of the Batesville ores are injured by any considerable percentage of silica: this ingredient varies from less than 2 per cent to about 8 per cent, though in some of the low grade ores it occasionally runs over 20 per cent. By far the greater part of the ore shipped, however, contains under 10 per cent and a considerable portion of it contains under 5 per cent. Very little is shipped that has as much as 15 per cent. Hence it will be seen by referring to the table of analyses, that the Batesville manganese ores compare favorably in their low silica with the ores from other localities, showing as they do, a smaller amount of this impurity than any of the others.

The only harmful ingredient that occurs in the Batesville ores in quantities sufficient to be injurious, is phosphorus. Though this often exists in quantities less than 0.125 per cent, it sometimes runs up to 0.30 per cent, and occasionally though rarely, to as much as from 1.00 to over 3.00 per cent. Considerable quantities of ore, however, are at present being mined which contain only between 0.10 and 0.20 per cent, and the average of the better grades of ore in the Batesville region generally ranges from 0.10 to 0.25 per cent. Some of the ores, however, are greatly injured in their market value, and in certain cases rendered unmarketable, by containing larger percentages of phosphorus.

The distribution of phosphorus in different parts of the ore deposits is irregular: sometimes the ore in a given place contains less than 0.20 per cent of phosphorus, while perhaps

* The analyses of Arkansas ores in this table are of samples from the Batesville region and not from the southwestern Arkansas region.

not ten yards off, apparently the same ore contains over 0.30. A study of the nature of the ore in each individual locality, however, and a series of analyses of properly selected samples, will usually show what part of a certain deposit contains a large amount of phosphorus and what part contains a small amount. In this way numerous areas of ore deposits low in phosphorus can be selected and the manganese obtained without any great admixture of less pure ores.

Summary.—The facts relative to the commercial value of the Batesville ores, as illustrated by their chemical analyses, may be summarized as follows: Considering the ores as a whole, their strong points are their high percentage of manganese and their low percentage of silica.* Their only weak point is their occasional high contents of phosphorus. This ingredient, however, is only in some cases in injurious quantities, while in a great many others, it is not high enough to be any detriment to the value of the ores. By carefully selecting localities to be worked and by properly preparing the ore for market, this difficulty can, in many cases, be largely overcome, even in the localities of high phosphorus ores.

The composition of the Batesville ores, as represented in car-load shipments, is shown in the following tables. These include seventy-two analyses of samples taken from quantities of ore varying from one to seven car-loads. The total amount of ore sampled for the analyses probably amounted to about two thousand tons, and were mined in various parts of the Batesville region. Many analyses of hand samples of ore might be given, but the table is confined to those of car-load shipments since, as already stated, the latter represent the average composition of the ore in bulk far more accurately than the analyses of small samples.

Wherever it was possible, the locality at which each shipment of ore was mined, and the name of the company or individual producing it are given, as well as the quantity sampled and the name of the company or companies under whose direction it was sampled and analyzed.

* These statements refer only to the better grades of ore.

Analyses of car-load shipments of

No.	LOCALITY.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.
1	Southern mine, 14 N., 7 W., sec. 4...	53.12	2.30	2.75	0.165	4.40
2	" " " "	51.82	3.40	2.50	0.193	5.10
3	" " " "	50.75	4.27	3.52	0.184	5.40
4	" " " "	49.73	2.15	3.10	0.166	7.28
5	" " " "	51.77	2.38	3.18	0.128	1.68
6	" " " "	49.60	3.84	4.79	0.184	3.88
7	.....	55.78	3.32	2.30	0.148	3.00
8	.....	56.20	3.07	2.70	0.124	3.20
9	.....	55.49	3.69	4.58	0.141	3.30
10	.....	52.72	3.85	2.44	0.198	4.00
11	.....	50.14	3.50	2.95	0.165	3.00
12	.....	53.02	1.90	1.70	0.352	3.00
13	Lafferty Creek divide	52.11	.....	.....	0.134	.....
14	" " " "	55.41	.....	.....	0.118	.....
15	" " " "	45.56	4.50	5.78	0.165	.....
16	" " " "	46.21	3.00	10.05	0.157	.....
17	" " " "	48.39	5.98	2.80	0.288	.....
18	" " " "	46.60	5.94	3.00	0.331	.....
19	" " " "	39.52	14.23	4.80	0.6 5	.....
20	" " " "	49.00	9.00	8.00	0.880	.....
21	" " " "	44.66	9.46	3.65	0.391	.....
22	Coon Creek.....	50.81	2.90	2.50	0.126	.....
23	Coon Creek, 14 N., 6 W., sec. 2	46.86	8.53	4.25	0.128	2.50
24	Coon Creek.....	49.36	5 97	3.90	0.156	5.50
25	14 N., 6 W., sec. 18	55.68	2.00	.....	0.172	.....
26	" " " "	53.66	2.50	.....	0.209	.....
27	" " " "	51.86	7.80	.....	0.141	.....
28	" " " "	42.77	5.50	.....	0.523	.....
29	Castile tract, 14 N., 6 W., sec. 18.....	55.45	2.95	5.60	0.117	1.30
30	" " " "	57.13	1.89	5 39	0.078	1.30
31	14 N., 6 W., sec. 18	56.10	2.61	5.44	0.075	0.60
32	" " " "	57.01	2.05	5.33	0.072	0.80
33	" " " "	57.41	1 62	6.00	0.100	1.00
34	" " " "	55.70	1.85	6.71	0.078	0.80
35	" " " "	56.75	2.19	5.49	0.068	0.20
36	" " " "	57.39	1.55	5.46	0 074	0.10

manganese ores from the Batesville region.

Mined by.	Quantity sampled.	Sampled by.	Analyzed by.	No.
Keystone M. and I. Co.	5 cars	Keystone M. and I. Co.	Keystone M. and I. Co.	1
" " "	" "	" " "	" " "	2
" " "	.....	" " "	" " "	3
" " "	5 cars	" " "	" " "	4
" " "	1 car	" " "	.....	5
" " "	4 cars	Carnegie Brothers & Co.	Carnegie Brothers & Co.	6
.....	5 cars	.....	.....	7
.....	" "	.....	.....	8
.....	" "	.....	.....	9
.....	.....	.....	Carnegie Brothers & Co.	10
.....	.....	.....	" " "	11
.....	.....	.....	.....	12
.....	1 car	.....	Missouri Furnace Co.....	13
.....	" "	.....	" " "	14
.....	7 cars	.....	" " "	15
.....	5 cars	.....	" " "	16
Missouri Furnace Co....	" "	Carnegie, Phipps & Co.	Carnegie, Phipps & Co....	17
" " "	" "	" " "	" " "	18
" " "	" "	" " "	" " "	19
" " "	" "	" " "	" " "	20
" " "	" "	" " "	" " "	21
J. B. Gray.....	1 car	Carnegie Brothers & Co.	Carnegie Brothers & Co.	22
" " "	" "	" " "	" " "	23
" " "	" "	" " "	" " "	24
Abbot & Ring.....	" "	North Chicago R.M.Co.	North Chicago R. M. Co.	25
" " "	" "	" " "	" " "	26
" " "	" "	" " "	" " "	27
" " "	" "	" " "	" " "	28
Skinner & Abbot.....	" "	Illinois Steel Company.	Illinois Steel Company.	29
" " "	" "	" " "	" " "	30
" " "	" "	" " "	" " "	31
John B. Skinner..	" "	" " "	" " "	32
" " "	" "	" " "	" " "	33
" " "	" "	" " "	" " "	34
" " "	" "	" " "	" " "	35
" " "	" "	" " "	" " "	36

Analyses of car-load shipments of manganese

No.	LOCALITY.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.
37	14 N., 6 W., sec. 18.....	38.49	8.80	19.96	0.115	7.00
38	" " "	56.65	1.68	5.55	0.066	0.80
39	" " "	58.31	1.33	5.78	0.064	0.90
40	Maxfield tract, 14 N., 6 W., sec. 30	44.69	9.18	8.23	0.319	.....
41	" " "	41 08	10.75	.....	0.467	.....
42	" " "	43.12	12.50	1.54	0.339	.....
43	" " "	42.74	4.95	10.41	0.385	.....
44	" " "	31.90	11.20	20.50	0.347	.....
45	" " "	24.31	21.63	14.82	0.252	.....
46	" " "	24.50	28.72	5.22	0.226	.....
47	" " "	27.49	23.40	7.08	0.405	.....
48	" " "	29.57	23.40	5.10	0.452	19.00
49	" " "	31.56	21.47	6.75	0.385	16.40
50	" " "	26.82	24.42	7.33	0.273	16.20
51	" " "	27.55	24.00	7.46	0.268	15.50
52	" " "	30.55	21.70	6.48	0.328	15.00
53	" " "	33.21	18.80	6.05	0.194	15.10
54	" " "	30.55	21.70	6.48	0.328	15.00
55	" " "	31.35	20.70	4.49	0.581	14.50
56	" " "	37.59	12.70	5.56	0.357	18.20
57	" " "	34.38	17.70	4.03	0.476	21.50
58	" " "	36.05	15.50	4.87	0.279	18.30
59	" " "	37.27	15.30	4.55	0 481	21.10
60	" " "	28.69	23.00	5.42	0.788	20.00
61	" " "	33.80	16.85	5.70	0.596	19.10
62	" " "	34.03	11.20	3.65	0.732	16.30
63	" " "	36.18	14 70	3.97	0.606	18.50
64	" " "	35.40	15.70	4.35	0.735	16.30
65	" " "	36.86	15.20	3.68	0.585	12.00
66	14 N., 6 W., sec. 33.....	38.30	8.45	.....	0.380	.....
67	" " "	39.35	5.30	.....	0.217	.....
68	Baxter mine, Wood & Sipes mine...	45.02	7.37	8.88	0.224	4.10
69	" " "	37.93	12.12	6.52	0.641	6.30
70	Baxter mine, 15 N., 6 W., sec. 32...	55.60	8.78	24.58	0.149	9.80
71	" " "	47.70	4.77	10.98	0.284	9.20
72	" " "	45.77	4.67	14.06	0.342	8.20

ores from the Batesville region—Concluded.

Mined by.	Quantity sampled.	Sampled by.	Analyzed by.	No.
John B. Skinner.....	1 car	Illinois Steel Company.	Illinois Steel Company.	37
" " "	" "	" " "	" " "	38
Skinner & Abbot	" "	" " "	" " "	39
Abbot & Ring.....	" "	North Chicago R.M. Co.	North Chicago R. M. Co.	40
W. S Abbot.....	" "	Illinois Steel Company.	Illinois Steel Company.	41
" " "	" "	" " "	" " "	42
Abbot & Ring.....	" "	North Chicago R.M. Co.	North Chicago R. M. Co.	43
" " "	" "	" " "	" " "	44
" " "	" "	" " "	" " "	45
W. S. Abbot.....	" "	Illinois Steel Company.	Illinois Steel Company.	46
" " "	" "	" " "	" " "	47
" " "	" "	" " "	" " "	48
" " "	" "	" " "	" " "	49
" " "	" "	" " "	" " "	50
" " "	" "	" " "	" " "	51
" " "	" "	" " "	" " "	52
" " "	" "	" " "	" " "	53
" " "	" "	" " "	" " "	54
" " "	" "	" " "	" " "	55
" " "	" "	" " "	" " "	56
" " "	" "	" " "	" " "	57
" " "	" "	" " "	" " "	58
" " "	" "	" " "	" " "	59
" " "	" "	" " "	" " "	60
Skinner & Abbot.....	" "	" " "	" " "	61
" " "	" "	" " "	" " "	62
" " "	" "	" " "	" " "	63
" " "	" "	" " "	" " "	64
" " "	" "	" " "	" " "	65
Abbot & Ring.....	" "	North Chicago R.M. Co.	North Chicago R. M. Co.	66
" " "	" "	" " "	" " "	67
Skinner & Abbot.....	" "	Illinois Steel Company.	Illinois Steel Company	68
" " "	" "	" " "	" " "	69
" " "	" "	" " "	" " "	70
" " "	" "	" " "	" " "	71
" " "	" "	" " "	" " "	72

CHAPTER VIII.

THE BATESVILLE REGION OF ARKANSAS—*Continued.*

GENERAL FEATURES OF THE MANGANESE DEPOSITS.

The manganese ores of the Batesville region occur as loose masses of variable sizes imbedded in a red or chocolate-brown clay. The clay and the ore once formed part of a formation already mentioned as the St. Clair limestone, and locally known as "gray rock." By the dissolving process of surface waters, the carbonate of lime in this formation has been leached out and the masses of ore, which were less easily attacked, have been set free. The siliceous material, which was once finely disseminated through the limestone, was also less soluble than the carbonate of lime in surface waters, and has collected as a residual product, forming the clay in which the ore occurs.

As a result of this decay, the manganese ore is now rarely seen in place in the limestone, but sometimes masses of this rock have survived decomposition and are imbedded in the residual clay. These masses often contain layers and nodules of ore, which, from their nature and position, point clearly to the St. Clair limestone as the source of all the manganese now found in the clay.

It will be the object of the present chapter to explain the original mode of occurrence of the ore in the limestone, the mode of decay of the limestone and the formation of the deposits of ore-bearing clay, the nature and distribution of these deposits, and their relations to the topographic and structural features of the region.

THE ST. CLAIR LIMESTONE.

General features.—The geologic relations of this lime-

stone have already been treated in chapter VI, and, therefore, the details given below are confined to the relation of the formation to the source and occurrence of manganese ores.

The St. Clair limestone is a highly crystalline, granular rock, reaching a maximum thickness, in the manganese region, of over a hundred and fifty feet. It is rarely, however, seen with this thickness, and, even where none of it has been decomposed, it does not usually exceed a hundred and twenty feet. It varies in color from light gray to pink, chocolate-brown, or dark lead-gray. Frequently pockets and veins of white or transparent calcite are found in it. Fossils are plentiful, and their casts have assumed the same crystalline structure as the rest of the limestone. Sometimes small quantities of red oxide of copper, or green stains due to carbonate of copper, occur at or near the base of the formation. The copper is always in very small quantities and of no commercial value. (See Montgomery manganese mine). A light greenish clay sometimes occurs in thin seams in the rock. The most remarkable feature of the formation, however, is the manganese ore that it contains.

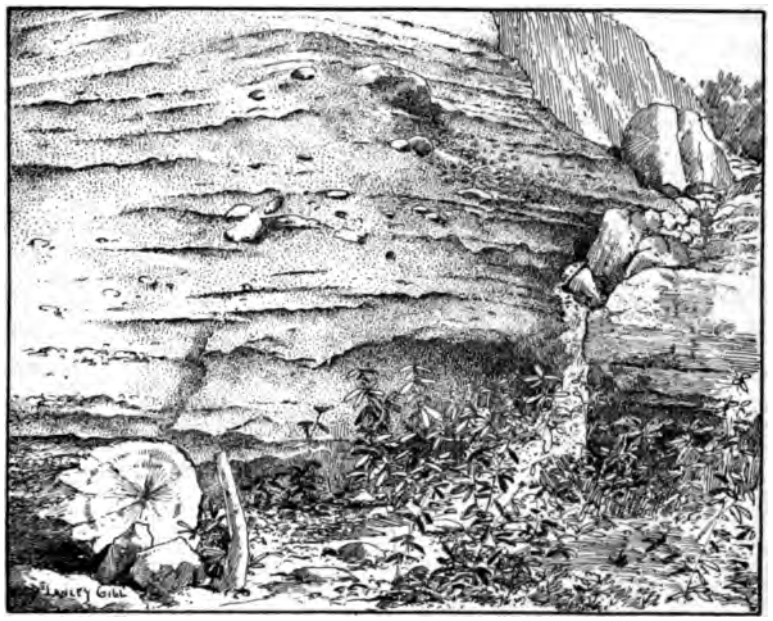
Condition of the manganese in the St. Clair limestone—The manganese, as seen in the St. Clair limestone, exists in the same, or almost the same, chemical and physical condition as in the clay that now encloses it in the various manganese localities; that is, it occurs as oxides in bodies of different sizes. It is very probable that the manganese originally existed in the limestone in the form of a carbonate and was subsequently oxidized into its present condition. Possibly this oxidation may be only superficial, and below the water level of the country the ore may still retain its carbonate form. Small quantities of the carbonate sometimes exists in a finely disseminated state in the limestone, even on the surface, but practically all the manganese in the limestone, as now seen in surface exposures, is in the oxide state, and the disseminated carbonate is insignificant in comparison with the larger masses of oxides.

It is very possible that, in some cases, the manganese oxide in the limestone may be in a different stage of oxidation from that in the clay, and may, therefore, represent a different miner-

alogical form of oxide; but in many cases, at least, the ores in both positions seem to represent the same oxide or oxides. Very often the ore in the limestone contains small inclusions of more or less pure, crystalline calcite; while, where the ore occurs in the clay, the inclusions have sometimes been leached, leaving hollow cavities which give the ore a honeycombed appearance. The cavities are often partly filled with red, yellow or dark brown clay, representing the residual product of the calcite. Sometimes, however, especially in the more compact ore, the calcite remains in its original form, even when the ore has been freed from the limestone for a long time.

The shape of the ore bodies in the limestone varies considerably in different places, but always conforms, in a general way, to the bedding of the rock. The ore occurs as irregular lumps and masses, often connected by thin layers of the same material; as lenticular bodies, a few feet to several yards in length; as flat masses or small concretions lying in the planes of bedding of the rock; as small disseminated particles and nodules, the size of small shot; and, in some places, in so fine a state of division as to form a dark chocolate-brown coloring matter. This last form sometimes occurs in thin layers in the rock and sometimes as a finely disseminated material, giving the dark brown color often seen in the limestone. When considerable quantities of it are present, the rock often loses part of its highly developed crystalline structure and presents a dark, earthy appearance. The larger masses of ore occur both in this dark colored, and in the light colored rock. In the latter case, they are usually associated with more or less red clay, either in the form of a thin coating around the masses of ore or as films between layers of ore.

A characteristic mode of occurrence of the manganese in the St. Clair limestone is shown in the accompanying drawing. It represents the partly decayed surface of the rock, which has been exposed in a pit on the William Martin property, in township 14 N., 8 W., section 2. The mass of the rock is a brown, or brownish-gray limestone, and the protruding knobs



THE DECAYED SURFACE OF THE ST. CLAIR LIMESTONE ON THE WILLIAM MARTIN TRACT, BATESVILLE REGION, ARKANSAS.

and horizontal layers are manganese ore in the process of weathering out.

Another case of somewhat similar occurrence is shown in the accompanying figure 9. This represents a cross section of a mass of St. Clair limestone protruding into the overlying ore-bearing clay in a pit at the Trent mine, 14 N., 6 W., section 10. The limestone here is of the light gray variety.

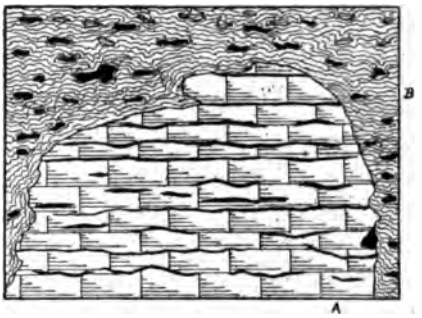


Figure 9.—Section showing the manganese ore in the St. Clair limestone and in the overlying residual clay at the Trent mine.

A. St. Clair limestone.

B. Residual ore-bearing clay.

The black markings indicate manganese ore.

The light colored masses in the clay, near the top of the section, represent chert fragments.

Horizontal and vertical scale: 1 inch—6 feet.

Frequently there are found at various horizons in the St. Clair limestone, beds of siliceous or argillaceous material, sometimes containing manganese and sometimes entirely free from it. These, in places, occur as fine grained, fissile sandstones, or as stratified shaly clays, while elsewhere they exist as highly siliceous slaty materials. They are often more or less calcareous. In color, they vary from chocolate-brown to red, dark yellow, or mottled red and gray. Such deposits form lenticular beds in the limestone and, though they have a limited lateral extent, they sometimes acquire a thickness of as much as thirty feet or more. They represent simply a greater development of the smaller quantities of siliceous and argillaceous materials which are almost always associated with the ore. The ore, when it exists in them, occurs in the same way as in the limestone, except that the concretionary form is more marked. Sometimes

these beds are entirely absent, and at other times two or more are seen in one vertical section of the formation. Such beds are well developed at the Cason and O'Flinn mines. (See chapter IX).

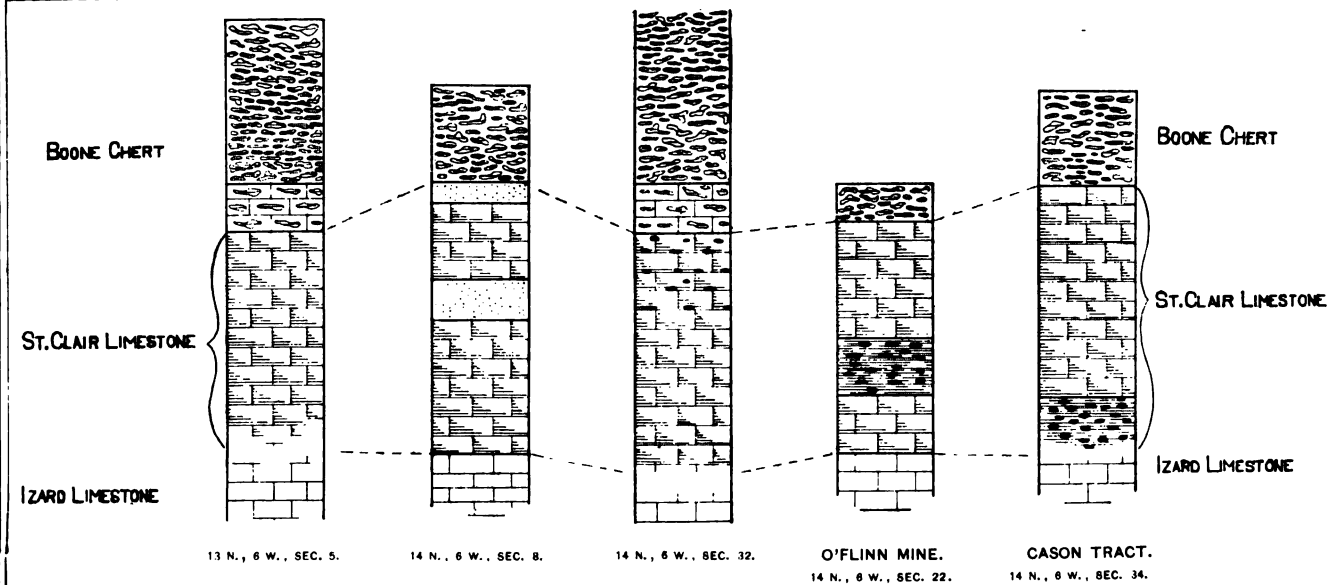
Siliceous deposits also occur, with the limestone, in the neighborhood of Cushman and thence west to Lafferty Creek and east to Prairie Creek. In this region they are sometimes composed of a soft, earthy material, and at other times of a fine grained sandstone, in which a coarser sandstone occasionally occurs. Iron is generally present, either in thin, rusty seams, or as flat lenticular concretions of limonite.

Columnar sections, showing the St. Clair limestone with and without sandstone beds, are given on plate VI.

A microscopic examination, made by Dr. J. E. Wolff, of Harvard University, of a calcareous sample from one of these sandstone beds at the Cason property, three miles northeast of Batesville, shows it to be composed of rounded and angular grains of detrital quartz, with a few feldspar grains and still fewer plates of detrital mica, cemented in a matrix of grains of calcite, mixed with red iron oxide or hydrate. The quartz, feldspar and mica appear to have been derived from granitic rocks. The subject of the composition of these beds will be mentioned further under the discussion of the origin of manganese deposits in the final chapter.

Distribution of manganese in the St. Clair limestone.—Manganese is not confined to any special horizons in the limestone but is apt to occur in it anywhere from the base to the top, and in varying quantities. Over limited areas the richest ore-bearing stratum is often fixed in position, but this does not hold throughout the whole region. At the Southern mine, where the St. Clair limestone has been almost entirely decayed, and where more manganese has been mined than at any other locality in the Batesville region, it seems probable that the ore originally occupied the upper part of the limestone formation. It does not necessarily follow from this, however, that the ore elsewhere was originally most abundant in this position.

The sections in the accompanying plate show the distribution



SECTIONS OF THE ST. CLAIR LIMESTONE SHOWING THE COMPOSITION OF THE FORMATION IN DIFFERENT PLACES.

THE BLACK PARTS INDICATE MANGANESE ORE.

of manganese in the different parts of the St. Clair limestone: the first two sections are from localities where no manganese occurs in the limestone; while the last three, from localities where it does occur, illustrate the existence of the ore in the upper, middle, and lower parts of the formation, sometimes associated with siliceous deposits, and at other times free from such accompaniments. The ore in any one position in the limestone may occur either with or without these siliceous materials. As a rule, however, the part of the limestone carrying ore contains more siliceous and argillaceous matter, than the part carrying none.

The lateral distribution of the ore is even more irregular than the vertical distribution. Manganese in small quantities is characteristic of the whole of the St. Clair limestone formation in the Batesville region, and an analysis always shows at least a fraction of a per cent of that ingredient, but it is only locally that ore exists in it in quantities sufficient to give rise to manganese deposits after the rock has decayed; and the areas of ore-bearing limestone are often surrounded by much larger areas of barren limestone. This irregular occurrence of the ore in the limestone is the cause of its equally irregular occurrence as now found in the residual clay.*

In a similar manner the Batesville manganese region, considered as a whole, represents an isolated manganese-bearing area in the St. Clair limestone. The belt of country in which the St. Clair limestone crops out, strikes in a general northwest and southeast direction, and extends, on both sides, beyond the manganese area. Outside the limits defined by a dotted red line on the map, however, manganese has not yet been found in any considerable quantities. An analysis generally shows a fraction of a per cent or more, just as in the barren parts of the rock in the Batesville region, but the larger masses and bodies of ore rarely occur.

* Good exposures of the manganese-bearing parts of the St. Clair limestone are rare, as hey are generally covered by the broken chert which covers a larger part of the region. It is only occasionally, in the face of a bluff or in the loose masses found in the residual clay in manganese pits, that such exposures can be observed. The above facts concerning its various constituents, therefore, are the result of numerous scattered observations taken over a large area.

Isolated areas of manganese deposits have been reported as existing in association with the St. Clair limestone to the northwest of the Batesville region, but they have not as yet proved to be of large extent, though future explorations may possibly show them to be so. Therefore, according to the present state of knowledge, the Batesville region represents an abnormal, local accumulation of manganese in a formation which, though characterized throughout by a certain amount of that material, contains it usually in limited quantities. The manganese localities to the northwest may be considered as representing a tendency towards a similar local accumulation, which, however, reaches only limited proportions. Therefore, though the St. Clair limestone is often considerably decayed in the country outside the manganese region, the ore deposits are wanting.

It is also a noticeable fact that the St. Clair limestone reaches its greatest thickness approximately in the manganese region. To the east, it rapidly thins out, and in less than ten miles either disappears altogether or is represented by only a thin stratum. To the west, it retains its full thickness for a short distance, but finally thins out in the same way as to the east.*

The Izard limestone, which underlies the St. Clair limestone, thins out in the same manner as that rock to the east and the west; and both formations may be said to reach their maximum development in the western part of the manganese region.

Color of the St. Clair limestone.—It has already been stated that the color of the St. Clair limestone is not uniform. The rock is usually gray or light pink, and from this it varies to chocolate-brown, reddish-brown, or a dark lead-gray.

The chocolate-brown color seems to be due to oxides of manganese and iron in a finely divided state, as is suggested by the considerable amount of these ingredients in the rock of that color, and by the fact that the intensity of the color varies directly with the amount of them present. Sometimes both oxides occur and sometimes only one is present. But the color is usually

* See page 125.

much the same whether the rocks contain both manganese and iron or either one of them separately.

The pink color in the St. Clair limestone also seems to be due to manganese and iron, probably in different stages of oxidation than the forms which give the chocolate-brown color. The pink specimens may contain both materials or either one, with very much the same coloring effect. Some distinctly pink specimens contain very small percentages of either of these ingredients, but as the rock does not contain any other color-giving constituents, it seems probable, though not necessarily certain, that the color is due to one or both of them.

Some of the pure gray limestone, which is the most common form in the region, contains only a trace of manganese and very little iron.

The following analyses, by the chemist of the Survey, show the compositions of the differently colored parts of the St. Clair limestone.

Analyses of differently colored St. Clair limestone.

CONSTITUENTS.	Chocolate-brown.	Chocolate-brown.	Pink.	Gray.
Manganese oxide (Mn_3O_4)...	1.59	1.24	0.26	trace.
Ferric oxide (Fe_2O_3).....	0.56	2.49	0.19	0.24
Alumina (Al_2O_3).....	0.37	0.61	0.18	0.06
Lime (CaO).....	54.75	51.62	54.70	54.76
Magnesia (MgO).....	0.29	0.28	.....	0.25
Potash (K_2O)	0.01	0.02	0.78†	0.78†
Soda (Na_2O).....	0.25	0.31		
Volatile matter*.....	42.31	42.46	43.35	43.19
Silica (SiO_2).....	0.25	1.00	0.54	0.54
	100.38	100.03	100.00	100.00

* This is mostly carbonic acid and some water. There is only a small quantity of organic matter present in any of the specimens and in some of them there is none. It does not appear to have perceptibly influenced the color, as the latter is still retained after ignition.

† Determined by difference.

Summary.—Thus it will be seen that the most characteristic feature of the St. Clair limestone is its contents of manganese ore;

that this ore occurs in a great variety of forms, from lenticular pockets and masses weighing a ton or more, to small concretions and grains, and even to impalpable coloring matter in the rock; that it is associated with a variable amount of siliceous or argillaceous material, sometimes occuring in the limestone almost free from such accompaniments, and sometimes buried in sandy or shaly beds, from one to thirty feet in thickness; that the ore is very irregularly distributed through the limestone, both laterally and vertically; that, when it occurs, it is not confined to any special horizon, sometimes existing at or near the top and sometimes at or near the base, as well as at various intermediate stages; that the Batesville region, considered as a whole, represents an isolated manganese-bearing area in the St. Clair limestone; that sometimes iron is found in association with the manganese, generally as a brown hematite (limonite) or as a rusty coloring material.

THE DERIVATION* OF THE MANGANESE DEPOSITS.

Condition of workable deposits of ore.—The deposits of manganese ore in the Batesville region *that can be profitably worked* are not found in place in the limestone. One exception is the Cason property, and even this is not worked for reasons that will be mentioned in chapter IX. In other cases, the quantity of ore, so far as yet discovered, is not sufficient to pay for mining it in the rock; and it is only where the limestone, or "gray rock," as it is commonly called, has been decayed, the carbonate of lime carried off in solution, and the masses of ore with the residual clay thus set free and concentrated, that profitable mining can be done. This decay has taken place on an immense scale, and all the deposits that are being worked, and all that have been worked in the past, with the exception of the Cason mine, represent such products of decay.

Mode of decay of the St. Clair limestone.—The St. Clair limestone is composed of two different classes of constituents: materials

* The term *derivation* is used here in distinction from *origin*, to express the process of formation of the manganese deposits as they now exist, by the decay, in situ, of the St. Clair limestone. The origin of the ores, in the sense of their source and mode of deposition in the limestone, will be treated in the final chapter.

readily soluble in surface waters, and materials either more difficultly soluble or almost insoluble. The first class is represented by carbonate of lime, which forms by far the larger part of the formation; the second class is represented by the manganese ores with their siliceous and argillaceous accompaniments. Surface waters always contain a greater or less amount of carbonic acid in solution, and this renders them much more potent as disintegrating agents than pure water. The effect of the long continued action of surface water on the ore-bearing limestone, has been to dissolve and carry off the carbonate of lime, and leave the masses of ore and other insoluble materials as a residual product, in the form of ore-bearing clay. In places where the St. Clair limestone contained the sandy and argillaceous beds already described, these have been broken up during the leaching of the enclosing limestone and, in some places, have been disintegrated into a more or less sandy clay, and mixed with the other residue from the limestone; in other places, they have not as yet been entirely decomposed and are associated with the clay as soft, earthy, honeycombed, and partly disintegrated masses commonly known as "ochre".* A small portion of the manganese has doubtless been carried away in solution, but a larger part of it remains. (See page 182.)

The St. Clair limestone occurs, in the manganese region, under a heavy bed of Boone chert, and the dissolving action which has leached the limestone has often gone on underneath the chert, as is explained below.

Stages of decay of the St. Clair limestone.—Throughout the manganese region, all stages of decomposition of the limestone, and all stages of erosion of the residual products can be seen. Sometimes the limestone is exposed in its full thickness, and shows no sign of decomposition. This is especially true along its extreme southerly outcrop, where it rises from under a heavy, protecting cap of chert. But to the north, it has succumbed more and more to decomposing influences, and has finally dissappeared altogether,

* This word is also used at the Southern mine to designate a certain deposit, of a somewhat similar nature to those described, occurring at the base of the chert beds, and immediately above the residual clay.

leaving nothing but the residual clay and ore, the skeleton, as it were, of the original limestone formation. As long as the limestone has remained intact, the massive chert which overlies it, has protected it to a greater or less extent from decomposition. But as soon as the dissolving action has set in, the residual clay sinks down and allows the overlying chert to settle down on it. In this way the chert bed is shattered and broken, allowing the free percolation of surface waters and greatly accelerating the decomposition of the limestone. The more carbonate of lime that is dissolved from the limestone, the more the chert is undermined and broken, and the faster the remaining limestone is decayed.

The decay of the limestone begins at the top of the bed, and, generally, in places where it crops out on the sloping sides of ravines. These being the most exposed points, are attacked first, and thence the dissolving action spreads back into the hill and under the chert. Where the whole of the St. Clair limestone has decayed, the clay bed rests directly on the decomposing surface of the underlying Izard limestone. The latter formation is, in such cases, deeply scored by holes running, sometimes, forty and fifty feet into the rock and filled with residual products. In some cases the Izard limestone is not seen at all, and the ore-bearing clay and broken chert cover the slopes of the hill, coming in contact, below, with the sandstone that underlies that limestone. In such cases, however, the total disappearance of the Izard limestone is only apparent, since, when it begins to decay, the overlying clay gradually covers its slopes, extending lower and lower until it finally reaches the level of the sandstone and obscures the whole of the limestone. Yet a large part of the interior of the hills is still composed of the limestone, which rises up in the form of rounded domes, covered with a variable thickness of ore-bearing clay.

The four ideal figures in the accompanying plate show the different stages of this decomposition. The first figure (1) represents the St. Clair limestone ("gray rock") and its overlying chert in their original position, lying horizontally, or almost so. Beneath them, is the Izard or blue limestone, underlain in turn by the saccharoidal sandstone. In the second figure (2), a ravine has

IDEAL SECTIONS SHOWING THE FORMATION OF MANGANESE-BEARING CLAY FROM THE DECAY OF THE ST. CLAIR LIMESTONE.

BOONE CHERT MANGANESE-BEARING CLAY IZARD LIMESTONE
ST. CLAIR LIMESTONE SACCHAROIDAL SANDSTONE

FIG. 1. ORIGINAL CONDITION OF THE ROCKS.

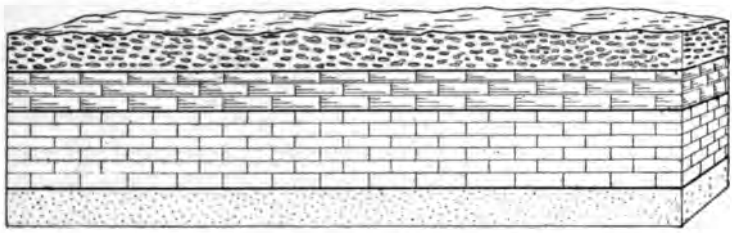


FIG. 2. FIRST STAGE OF DECOMPOSITION.

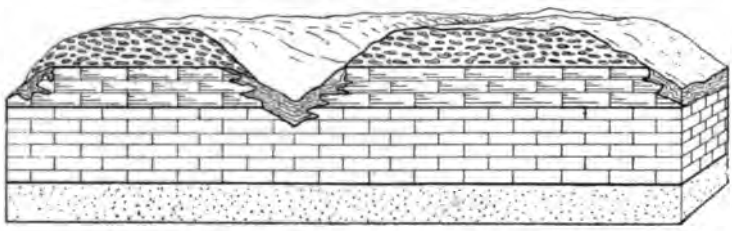


FIG. 3. SECOND STAGE OF DECOMPOSITION.

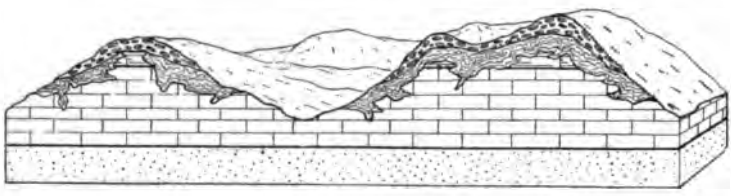
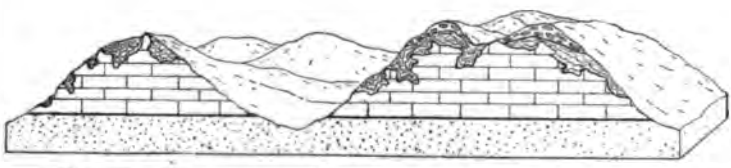


FIG. 4. THIRD STAGE OF DECOMPOSITION.



cut down through the chert and the St. Clair limestone. Decomposition has set in on the exposed limestone slopes and residual clay has collected in the hollows thus formed. The chert has already been broken on the slopes and has begun to curve down over the clay. In the third figure (3), the ravine has widened, and the decomposition has spread back into the hill, underneath the chert. The ore-bearing limestone has mostly decayed, while the chert has been greatly broken as a result of this undermining process, and has been partly eroded by the surface weathering. The residual ore and clay lie on the Izard limestone, which itself has been attacked by the leaching waters and scored with deep holes. In the fourth figure (4), the ravine has widened still more, and has cut through the Izard limestone and into the underlying sandstone. The whole of the St. Clair limestone has been decomposed, and the ore and clay lie on the deeply scored Izard limestone. The chert has been very much affected by erosion and, in some places, has been entirely removed; in others it exists as isolated knobs, or as a blanket of loose fragments on the slopes of the hills.* It will be observed that, where the chert is entirely removed, the ore-bearing clay has also suffered from surface erosion and has been partly carried off.

Effect of the decay of the St. Clair limestone on topography.—The four figures in the last plate also illustrate another important point, that is, the changes in the surface features of the country resulting from the decay and erosion of the limestone. The first figure shows the original flat character of the region. The second shows the initial stage in the alteration of this simple topography, by the erosion of long ravines or hollows. The third shows the widening of these ravines into valleys and the formation of numerous tributary drainage basins, giving the country a characteristic topography of irregular ridges transversely cut at intervals by the courses of streams. The fourth figure shows the still further decay and erosion of

* Though these figures are ideal, actually existing examples of every feature represented in them are seen in the manganese region, and figures of such cases are given later in this chapter, and also in the detailed descriptions of localities in the two following chapters. Ideal illustrations are given here in order to show as much as possible in a few figures and to illustrate better the different stages of decomposition.

these ridges, causing the formation of knobs and cone-shaped hills.

Unequal decay of the St. Clair limestone.—It has already been stated that exposures of the ore-bearing parts of the St. Clair limestone are rarely seen on the surface, as they are concealed by a covering of residual, ore-bearing clay. On the other hand, the parts not containing ore are often exposed in their full thickness, and this frequently happens in the immediate neighborhood of ore-bearing parts which have been completely, or almost completely reduced to their residual products. The difference in decay is seen even where both rocks were originally in equally exposed conditions and subject to identically the same decomposing influences. The cause of the difference therefore must be looked for in physical or chemical differences in the rocks. It is noticeable that the ore-bearing parts of the limestone, as a rule, though not invariably, contain considerably more earthy material* than the parts not containing ore. This gives a porosity to the rock and surface waters sink into it much more readily than they do into the purer rock, which is more dense and absorbs less moisture. Therefore, while the leaching of carbonate of lime in the earthy limestone goes on both inside and outside, the leaching of the purer rock is confined largely to the surface; and, consequently, the decay of the former is much more rapid than that of the latter.

Another cause that may have assisted in the rapid decay of the ore-bearing parts of the limestone is carbonic acid derived from the ore. The original condition of the manganese ore was probably that of carbonate. At present, at least in surface exposures, the ore is practically all in the oxide form. In the transition from carbonate to oxide, a considerable amount of carbonic acid would be given off, and this would have a potent effect in the decay of the limestone; while the part of the forma-

* These materials are not to be confused with the regularly bedded deposits of shaly and sandy materials already described in the St. Clair limestone. What is referred to here is simply the earthy material finely disseminated through the rock.

tion that did not contain ore would not be subjected to this action, and would therefore more effectually withstand decay.*

As a result of this unequal decay and also of the irregular and often abrupt manner in which the ore is distributed through the rock, the barren parts of the limestone frequently protrude through the partly enveloping residual clay of the ore-bearing parts. Hence isolated hills of pure limestone are sometimes surrounded on all sides by areas of residual clay; or, areas of residual clay are surrounded by reefs, as it were, of hills of pure limestone. Such occurrences are seen in the neighborhood of the Southern mine. This property represents an area of almost complete decay of the St. Clair limestone, yet on the north, south, east, and west of it are many isolated exposures of the same rock, but without ore, in a good state of preservation. Moreover, in the surrounding exposures, the rock is of a light gray color and often does not contain over 3 to 5 per cent of earthy materials, while the same rock at the Southern mine, judging from the products of decay, must have contained many times this amount.

CHEMICAL RELATION OF THE MANGANESE-BEARING CLAY TO THE ST. CLAIR LIMESTONE.

The relation of the St. Clair limestone and its residual, manganese-bearing clay is well shown in the chemical composition of these materials. The analyses given below represent the composition of the limestone and clay as they occur on the William Martin tract, on Lafferty Creek.† The limestone is of a dark chocolate-brown color, and consists of a granular, crystalline mass. The clay is of the same color as the limestone, but a shade darker, and is a highly plastic, impervious material. Both the limestone and clay originally contained masses of manganese ore. These were of considerable size and so unevenly distributed, that unless samples of several tons of both rock and clay were taken, their presence in the two beds could

* A somewhat similar decomposing action caused by carbonic and sulphuric acids derived from the oxidation of carbonates and sulphides of iron in the ore-bearing rocks of the Appalachian Mountains has been suggested by Professor J. D. Dana, Amer. Jour. Sci., Vol. CXIV, 1877, p. 138-139.

† See page 168, and also chapter X.

not be properly compared. Therefore, they were all removed from the samples taken, and the manganese shown in the analyses represents only that which was finely disseminated through the limestone and the clay.

Both samples were from the same pit. The clay was taken from a hollow in the surface of the limestone and was covered by about fifteen feet of a similar clay, which in turn was overlain by a protecting cap of chert. Therefore, any changes in the constituents of the clay, that might have taken place as a result of surface influences subsequently to its formation from the limestone, were reduced to a minimum.

The following analyses, made by the chemist of the Survey, show the composition of the two materials dried at 110°—115° Centigrade.

Analyses of the St. Clair limestone and its residual clay.

	Limestone.	Clay.
Manganese oxide (Mn_3O_4)	4.30	14.92
Ferric oxide (Fe_2O_3)	2.33	1.98
Alumina (Al_2O_3)	4.16	30.18
Lime (CaO)	44.51	3.89
Magnesia (MgO)	0.30	0.26
Potash (K_2O)	0.35	0.96
Soda (Na_2O)	0.16	0.61
Water (H_2O)	2.25	10.72
Carbonic acid (CO_2)	33.88	0.00
Phosphoric acid (P_2O_5)	3.02	2.53
Silica (SiO_2)	4.10	33.55
	99.36	99.60

It will be observed that the constituents of both the limestone and clay, though in different proportions, are the same, with the exception of carbonic acid. This, in the form of carbonate of lime, has been removed during the decay of the rock and is entirely absent in the clay. Possibly a small portion of it was combined as carbonates of some of the other bases present.

If all the constituents of the limestone had remained in-

soluble while the carbonate of lime was being removed, their percentages in the residual clay should have been increased in direct proportion to the amount of carbonate of lime abstracted. A comparison of the analyses, however, shows changes differing very much from this simple ratio. The proportion of silica has increased more than that of any of the other ingredients, while the alumina has increased very nearly as much. All the other constituents have suffered greater or less loss, and though, in most cases, the actual proportion that they form of the clay is larger than that which they form of the limestone, it is not nearly so large as it should be, had they been uninfluenced by the same leaching action that removed the carbonate of lime.

Assuming that the silica has remained absolutely insoluble, and that the quantity of it in the clay represents the total amount of it in the limestone from which the clay was derived, a basis is obtained on which the loss in other constituents can be determined.* Calculating both analyses to 100 per cent, it is found that the percentage of silica in the residual clay is 8.157 times that in the original limestone; or, in other words, it has taken 8.157 parts of limestone to give as much silica as is in one part of the clay. Hence, by multiplying each of the other constituents of the limestone by 8.157, figures are obtained which represent the amount of each of these constituents in 8.157 parts of limestone, or, what is the same thing, represent the quantity of each constituent that should remain had none of it been lost in the decay of the rock. By dividing each percentage in the clay by the corresponding quantity as obtained above, the percentage of each constituent saved during decay is obtained.

* It is probable that at least a small portion of the silica has also been carried off in the decay of the limestone, and, therefore, absolute quantities for the loss in the other ingredients, calculated on the basis of the entire insolubility of the silica, are too small; but the ratio of the percentages lost in each ingredient will remain the same, whether the silica was absolutely insoluble or whether it was partially dissolved. Therefore, in the absence of evidence as to how much of it has been removed, it is assumed, for the sake of simplicity in the following calculation, that all of it remains.

This calculation can be expressed in the following equations:

A=the per cent of a given constituent in the clay.

B=the per cent of the same constituent in the limestone.

X=the per cent of the same constituent saved.

Y=the per cent of the same constituent lost.

$$\frac{A}{B \times 8.157} = X \qquad 100 - X = Y.$$

The following table has been compiled by calculating to 100 per cent the analyses of limestone and clay already given, and from them obtaining the percentages of the ingredients of the limestone saved and lost during decay, as just explained.

Chemical changes in the decay of the St. Clair limestone.

Constituents.	ANALYSES. Limestone.	Clay.	Percentage of constituents of the limestone saved in the clay.	Percentage of constituents of the limestone lost in the clay.
Manganese oxide (Mn_3O_4)	4.33	14.98	42.41	57.59
Ferric oxide (Fe_2O_3)	2.35	1.99	10.44	89.56
Alumina (Al_2O_3)	4.19	30.30	88.65	11.35
Lime (CaO)	44.79	3.91	1.07	98.93
Magnesia (MgO)	0.30	0.26	10.62	89.38
Potash (K_2O)	0.35	0.96	33.63	66.37
Soda (Na_2O)	0.16	0.61	46.74	53.26
Water (H_2O)	2.26	10.76	58 37	41.63
Carbonic acid (CO_2)	34.10	0.00	0.00	100.00
Phosphoric acid (P_2O_5)	3.04	2.54	10.24	89.76
Silica (SiO_2)	4.18	33.69	100.00	0.00
	100.00	100.00		

It will be observed that the per cent of manganese oxide has been increased from 4.33, in the limestone, to 14.98 in the clay; also, that this 14.98 per cent in the clay represents only 42.41 per cent, or less than half, of the manganese that would have remained had none of it been lost in the decay of the rock. In other words, 57.59 per cent of the manganese oxide that was once finely disseminated through the limestone, has been lost in the conversion of that rock into residual clay. This amount has been carried off in solution, probably in the form of bicarbonate

of manganese, as further explained in the final chapter of this volume.

It has already been stated that the original samples of limestone and clay that were taken for analysis, contained large masses of manganese ore, but these were removed for reasons already stated, and what remained in the materials analyzed represented only the manganese that existed in a finely divided form. In this shape, the manganese would be much more rapidly taken up by surface waters than in the form of lumps, as a much larger proportion of surface is exposed to the dissolving action. Therefore, the above percentage of loss is greater than would be represented by the actual percentage of loss from the whole ore-bearing deposit, including both the lump and the finely disseminated ore. When the lumps of ore are exposed on the surface, they rapidly crumble into small particles and then into powder, in which form they are easily removed by the dissolving and eroding action of surface waters. But when they are buried in the clay, they are, to a large degree, protected by the impervious nature of that material, and retain their hard, massive form, suffering but little from the action of water. Therefore, it is safe to say, that, in the case in question, probably less than 25 per cent of the total manganese that was originally in the limestone has been lost during the transition into clay; also, that the loss was largely in ore in the finely disseminated state, in which it was unavailable for commercial purposes. The total loss in commercially valuable lump ore has probably not been ten per cent. In other places where the ore deposit is still better protected, the loss is probably less, while in the many cases where the deposit is less well protected, the loss has been greater.

One of the most noticeable features in the above table is the excess of loss in iron over that in manganese. This may possibly be due to different chemical conditions of the two ingredients, but it is more likely an accidental occurrence due to the limestone from which the clay was formed, having contained less iron or more manganese than the sample of limestone analyzed. The iron and manganese in the original limestone

were doubtless largely, if not altogether, in the form of oxides, as shown by the color of the rock and by the nature of the larger masses of these materials already referred to. A part of them may have been combined with the other acids present, but the amount, as compared with that in the oxide form, was small. Both metals have preserved their oxide form in the residual clay.*

As already stated, a larger part of the lime was combined as carbonate in the original limestone, but it will be observed that a small amount of it (3.91 per cent) exists in the residual clay, after all the carbonic acid has been removed. As the only other acids present in either the limestone or the clay are silicic acid and phosphoric acid, the presence of this remaining lime is probably to be explained by the existence of a small portion of it in combination with silica, or with phosphoric acid as tribasic phosphate of lime.

The large percentages of potash and soda saved, point to a more insoluble form for these ingredients than carbonates or phosphates, and it is probable that they were united in the limestone with a part of the silica in the form of complex silicates of alkalies and other bases.

The water in the residual clay may be in combination with silica and alumina in the form of hydrous silicates of alumina, or with alumina alone in the form of a hydrate of alumina.

NATURE OF THE MANGANESE DEPOSITS.

It has already been shown how the manganese ores of the Batesville region originally existed in the St. Clair limestone ("gray rock"), and how they were derived from that formation by its decay and by the concentration of the ore in the residual clay. It will now be the object to describe the nature of these deposits of residual ore-bearing clay and the relation of their mode of derivation to their economic development.

Distribution of ore in the clay.—The distribution of manganese ore in the clay, as would be expected from its unequal

* The original condition of the iron and manganese in the limestone may have been as carbonates, but later oxidation has converted them, at least in the surface exposures of the limestone, into oxides. (See page 167.)

distribution in the limestone, is irregular, and is the principal cause of the uncertainty in mining it. In some places, though rarely, it is evenly distributed throughout a large body of clay; but in most places it is in numerous pockets surrounded by clay containing no ore. These pockets vary greatly in character: sometimes they are comparatively solid bodies, separated only by thin films or seams of clay, and containing from fifty to five hundred tons or more of ore; sometimes they consist of large and small masses of ore imbedded together in greater or less quantities in certain places in the clay; at other times they are composed of small nodules or grains (called "wash dirt" or "shot ore" by the miners) disseminated throughout the clay. The mass of these pockets of "wash dirt" contain from five to twenty-five per cent of manganese ore. Sometimes large areas of clay contain little or no ore, just as large areas of the original limestone often hold enough insoluble material to form a clay bed, yet contain no manganese.

Effect of the unequal decomposition of the limestone on the pockets of ore.—As the bodies of ore in the original limestone tended, in a general way, to follow the almost horizontal bedding of the rock, and often had an oblong, flat shape, it would be expected that they would retain something of that shape in the residual clay. In most cases, however, the horizontal position has been considerably disturbed by the unequal decay of the limestone, and the flat bodies of ore have been broken into angular fragments, or crushed together in a shapeless, shattered mass. Sometimes the fragments of ore have been separated in the unequal sinking of the clay and have been carried to different depths. Where the ore originally existed in the limestone as separate nodules, the same agencies have tended to scatter them, thus still further dividing the deposits as they originally existed in the limestone. This action has undoubtedly, in many places, caused a more general distribution of manganese in the clay than was the case in the St. Clair limestone. Of course the aggregate amount of ore has not been increased, but the original pockets have been broken up and separated.

In some places, however, where the decaying limestone has

retained a comparatively even surface, the pockets of ore preserve their general horizontal position. Such is the case at the Southern mine, near Cushman, where, though the ore bodies sometimes pitch at high angles, a characteristic mode of occurrence is as almost horizontal pockets, gently undulating and of variable thickness.

It is also a noteworthy fact that, where the surface of the St. Clair limestone has been worn into the domes and peaks, already described, the clay and its accompanying ore have a distinct dip, pitching away from such protuberances on all sides. This feature is a natural consequence of the sinking of a soft, plastic clay on an uneven surface, and a knowledge of it will prove of value in the practical mining of the ore. When a body of ore is found in the clay at or near the surface of one of these limestone peaks, its dip will be found to conform more or less closely to the angle of slope of the surface of the limestone. Therefore the extension of the ore is to be looked for in such directions and not in the interior of the limestone, as is often thought to be the case. A large amount of time and labor has often been spent fruitlessly in blasting through bodies of limestone in hopes of finding ore in them, when, if there is any workable ore in the locality at all, it will be found in the clay enveloping the limestone, and not in that rock itself. As already explained in this chapter, the manganese has all been derived from the limestone, but it is only in the clay resulting from the decay of the limestone, that the ore can be profitably mined.* Hence the uselessness of attempting to blast into the limestone and the necessity of looking for the extension of the ore in the enveloping clay.

Nature of the clay.—The clay containing the ore is generally of a red, dark purple or chocolate-brown color, though sometimes it assumes a yellow color. It is soft and plastic when wet, but when dried, becomes a friable, earthy mass. It is frequently associated with greater or less quantities of sandy materials,

* For the exception to this rule see page 174, also chapter X.

such as have been already described as occurring in the original limestone.* (See page 169.)

The gradual and irregular sinking of the clay has caused numerous faults and joints in the deposit, running in all directions, both in straight and in curved lines. The faces of these disturbances are deeply scored, showing distinct marks of striation (slickensides) and a bright, highly glossy surface. When the clay is red, the slickensides are often of a brilliant crimson color; and when it is brown, they are of a very highly polished, black or dark brown color. Sometimes manganese in solution has been carried into these joints and has been deposited as a thick, black film or sheet.

Masses of St. Clair limestone in the ore-bearing clay.—Besides the bodies of ore found in the manganese-bearing clay, there also occur numerous loose masses of the original St. Clair limestone, representing parts of that formation which have so far escaped decay. These vary in size from a few inches to twenty feet or more in diameter, and have a rough, granular surface. They often contain more or less manganese, either in the form of nodules, seams, or a finely disseminated, brown coloring matter. Occasionally masses of ore protrude from their surfaces, as a result of the leaching of the limestone from around them. In such cases the ore is commonly thought by the miners to have been stuck to the surface of the rock, or, as they express it, to have been "welded on," but it is really a directly opposite process that is taking place, that is, the ore is being freed from the limestone. Fragments of the limestone, of a gray color and almost entirely free from manganese, often occur in the midst of the ore-bearing clay. The presence of these is easily explained when the nature of the original St. Clair limestone is understood.

* Where the overlying chert is thin or is represented only by scattered fragments, the surface of the ore-bearing clay is often cultivated. These fields are very productive, and their fertility is probably due to the large amount of phosphoric acid in the soil (0.25 per cent to over 2 per cent) and not, as is usually supposed, to the manganese. The latter substance is a desirable ingredient in the soil, as it forms a part of the mineral constituents of many plants. (see pages 2-3), but its presence is not sufficient to account for the productiveness in the present case. The presence of the chert fragments and rounded pebbles in the soil are also, to a certain extent, of advantage, for, though they increase the difficulty in plowing, they give a porosity to the clay which is needed in such an impervious material.

It is a common occurrence for strata of manganese-bearing parts of the limestone to be separated by barren parts, and, in the disintegration of the whole formation, the masses of the barren rock are mixed with those of the ore-bearing kind in the residual clay. Often, also, the manganese-bearing rock is softer and more earthy than the barren and purer limestone, and succumbs more readily to the dissolving action of water, causing a tendency for the number of pure masses to exceed that of the manganese-bearing kind. Though such is sometimes found to be the case, both kinds are of frequent occurrence in the clay.

In places the limestone masses occur in the upper part of the clay bed, with a depth of fifty feet or more of clay below them. That these loose masses have not been decomposed before enough of the underlying rock has decayed to form the great thickness of clay that is now beneath them, is probably due to the fact that the clay is very dense and has, to a great extent, protected them from the decomposing influence of surface waters; while the main mass of the rock below is exposed to the action of water constantly percolating at its line of contact with the base of the overlying clay. The same cause has probably operated in saving a large amount of the manganese ore set loose from the limestone, since, if this had been exposed to the disintegrating influences of air and water ever since it was freed from the rock, it would doubtless have been entirely carried away. A tendency to decay is seen in the porous, earthy crust that surrounds the interior harder part of the ore even when buried in the clay.

Conditions regulating the quantity of the ore-bearing clay.—The quantity of the residual clay varies greatly in different places, and is directly dependent on the amount of insoluble material that existed in the original limestone, and on the extent to which that rock has been decomposed. Sometimes it contains less than two per cent of insoluble material, the rest being almost entirely carbonate of lime; and in such cases the residue would be exceedingly small; in fact it would probably be imperceptible, as the waters that dissolved the carbonate of lime would tend to carry off this small amount in mechanical suspension. In places where the manganese ore is found, however,

the insoluble material generally forms a much larger percentage of the limestone, and sometimes, judging from the thickness of the residual clay, it must have composed as much as a quarter or more of the whole mass of the rock. This is the reason why there is little or no residual clay in many places where the whole of the limestone has been decomposed, while in others, where even only a part of the limestone has decayed, there are large deposits of it. Surface erosion may, in some cases, be responsible for the removal of the clay, but where such deposits have a protecting cap of chert, the influence of this factor in its removal is small. Again, when the amount of ore and insoluble matter in the rock is the same in two places, there will, of course, be the largest deposit of clay and its accompanying manganese in that place where the greatest amount of decomposition of the limestone has gone on, since, where the rock has not decayed, the clay and ore are still locked up in it. Here, therefore, is a most important factor in the determination of the value of a manganese property in the Batesville region. If the St. Clair limestone is seen cropping out plentifully on a given hill, it may be confidently concluded that very little of it has decayed and that the ore-bearing clay, if it exists at all, will be of limited extent. On the other hand, if the St. Clair limestone does not crop out on the hill, and if it is evident from the nature of the surrounding region that it was there once* and that it no longer exists, then it must have decayed, and the manganese-bearing clay deposits can be looked for with the possibility of finding them, the amount of ore in them depending on the amount in the original limestone. If that rock contained no ore, the clay deposit will contain none; and if the rock was rich in ore, the clay will also be rich. The ore in the clay, however, will be in a more concentrated form than it was in the limestone, as the carbonate of lime in the latter has been dissolved out, and the ore and clay brought together as a residual product, representing often only a small part of the original rock.

* It has already been shown in chapter VI. that the rocks of the Batesville region lie almost horizontally. Therefore, it is easy to follow the continuation of any given formation on the slopes of the hills in the area of its occurrence, as it will crop out at approximately the same level in neighboring localities.

Between the stages of very little decay of the limestone and complete decay, there are all gradations in the decomposition of the rock and, therefore, all gradations in the possible extent of the ore-bearing clay.

Such reasoning as that used above will not afford exact estimates of the quantity of ore in a given place, as that depends absolutely on the amount of ore that was in the original limestone before it decayed. Therefore, the quantity of ore present must be determined by prospecting, but the principles set forth in the foregoing paragraphs, if carefully put into practice, will indicate very clearly the places that can be prospected with a reasonable possibility of finding ore, and the places where it will be useless to prospect. In this manner a miner going into the region can soon determine to what localities he should direct his attention, and thus save a great amount of unprofitable labor.

Time required for the accumulation of the ore-bearing clay.—Though the process of setting the ore free from the rock has, in many parts of the Batesville region, taken place on a large scale, it has been very slow, and the time required to decompose a large bed like the St. Clair limestone cannot be measured in years or centuries. The decay has been going on for geologic ages and is still going on at the present day. Doubtless, since the decay began, the St. Clair limestone has not only been decomposed in many places, but the resulting ore and clay as well as the chert capping, have been carried away by the long continued surface erosion. The deposits that are now left, therefore, are those that have been formed at a sufficiently recent date to survive this erosion.

Uncertain thickness of the ore-bearing clay.—As a result of the uneven manner in which the St. Clair limestone decays, sinking down in deep holes and leaving steep domes or peaks, and also of the equally uneven manner in which the Izard limestone decays after all the overlying formation has succumbed, the depth of the manganese-bearing clay is very changeable, even over limited areas. Practical tests have proved the thickness to vary all the way from a few inches to almost a hundred feet. A shaft may be sunk in clay forty or fifty feet deep in one

place, and perhaps twenty yards off the same clay is not ten feet deep. In the first case the shaft has struck a hollow in the the limestone; in the second, it has met with one of the domes or peaks of undecayed limestone. Frequently over a hundred feet of unaffected limestone are found in one place, while, less than half a mile away, the whole formation has been completely decomposed. A remarkable case of this is seen at and near the Southern mine, which is further mentioned in this chapter and also in chapter X.

THE CHERT CAPPING OF THE MANGANESE DEPOSITS.

Power of resisting erosion.—It will be seen, from what has already been said, that a considerable thickness of chert still exists in many places, even after the whole of the St. Clair limestone and a part of the Izard limestone have been removed from under it. This is due to the fact that, (1) the chert bed is composed of almost pure silica, which is insoluble, or almost so, in surface waters; (2) it is in the form of a hard flinty rock which strongly resists mechanical disintegration. Hence, while the more easily dissolved limestone below slowly succumbs to the influences of surface waters, and a large part of its mineral matter is carried away, the chert gradually sinks in to fill the cavities thus formed. During the removal of the underlying rock, however, the chert has not remained entirely unaffected. As already explained on page 129, the formation normally contains interstratified beds of limestone, and these have been leached out. Even the chert itself, though more resistant than the limestone, is by no means absolutely proof against the action of surface influences and has lost a large part of its original bulk. Though sometimes a considerable thickness of it is still left, yet, in many places, it has been almost entirely eroded away and the only indications of its former existence are a few angular fragments in the surface of the residual clay.

The thickness of the chert formation in the manganese region, where it is seen unaffected by weathering, varies from a hundred and twenty-five to over two hundred feet; but where the St. Clair limestone has completely decayed and the chert has

been let down upon the residual clay, it never has even the lesser thickness, and usually does not exceed thirty to sixty feet. Sometimes the chert has been locally turned on end in the subsidence that it has undergone, and in sinking shafts in such places it has occasionally been found necessary to go down over sixty feet before reaching the ore-bearing clay. This depth, however, does not represent the actual thickness of the chert bed, as the shaft is not sunk at right angles to the stratification, but obliquely to it, and therefore the thickness is exaggerated. Possibly, not fifty feet from such a place the chert may be more nearly horizontal, and another shaft may pierce less than half this thickness of the rock before reaching the clay. Such occurrences are common at the Southern mine, where the thickness of the chert capping, as estimated by shafts, varies from less than ten to over sixty feet.

Amount of subsidence of the chert.—The vertical distance which the chert has subsided can only be estimated from the thickness of the underlying limestone that has been removed. In the manganese region, the St. Clair limestone, when not decayed, varies from a hundred to over a hundred and fifty feet in thickness; and not only has this often been entirely decomposed, but a part of the underlying Izard limestone, also, has sometimes decayed. In estimating the subsidence of the chert, account must be taken of the residual clay that has remained, and, as the quantity of this is variable, its exact thickness is difficult to estimate accurately without a practical test. It is also difficult to determine definitely whether the underlying limestone, before it decayed, tended towards its maximum or its minimum thickness; but an approximation to the original thickness can generally be made by measuring the formation in the nearest places in which it is exposed in an undecomposed state. From a consideration of all these data, it is certain that the chert formation, or rather the part of it that remains, has, in many places, been let down as much as a hundred feet, and possibly, in some places, somewhat more. In cases of such extreme subsidence, however, it is rarely that a thickness of more than twenty or

thirty feet of chert is left; but subsidences of from forty to fifty feet are numerous, and in such cases a thickness of from thirty to sixty feet of chert often remains.

Effect of the subsidence on the structure of the chert.—The sinking of the chert has been an exceedingly slow process, and has gone on at the same time, and at the same rate, asthe slow decomposition of the limestone. It has, however, effected a great change in the structural condition of the formation as a whole, causing it to be much broken and faulted and curved into small, shattered anticlines and synclines, often dipping off at angles of from 45° to 60° or more, and much resembling those formed by lateral pressure. These chert disturbances are not due to lateral pressure, however, for the underlying rocks are either horizontal or dip gently to the south or southwest, and show no trace whatever of any disturbances like those that have affected the chert. It is also observable that, when the limestone has not been attacked, the chert overlying it shows no signs of disturbance; while, where the limestone has decayed, the chert has been affected, and the amount of disturbance depends directly on how much and how unevenly the limestone has been decomposed. It is invariably the case that, where the chert has been thrown into an anticline, its form is regulated by an underlying body of limestone, or by an especially abrupt accumulation of residual clay; and when it is in the form of a syncline, its structure is dependent on the intervals between similar inequalities. Frequently, also, the chert covers a projecting knob on all sides and dips off in the form of a cone. Thus the problem of the amount of disturbance in the chert reduces itself to a question of the contour of the decaying surface of the limestone.

The chert has assumed the contorted forms entirely by a series of fractures, and the result is that a section of the disturbed rock has the appearance of being loosely put together; yet, though the blocks and slabs of rock are often disconnected, the original continuity of the different parts can be clearly made out. Though the chert is a hard rock, it is very brittle, and when the underlying limestone is removed, it acts very much as would

a plate of glass if broken by being pressed down over an uneven surface. It is to this brittle quality that the chert owes its power of adapting itself to the undulations of the underlying surface.

When the chert becomes very thin, it loses all traces of former structure and occurs simply as an irregular heap of loose, angular fragments. As a result of this, a common feature throughout the manganese region is the occurrence of small abrupt hills of Izard limestone, overlain by ore-bearing clay and capped by prominent knobs of loose chert, covering sometimes only a few acres.

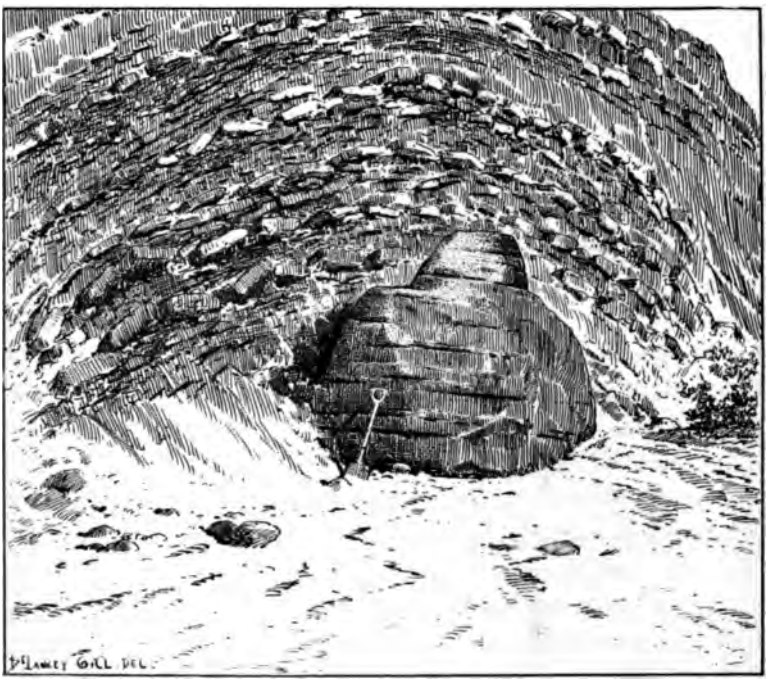
The accompanying drawing, made from a photograph, illustrates the disturbances in the chert as seen at the Grubb Cut,* one mile north of Cushman, and shows the dependence of these disturbances on the shape of the decayed surface of the underlying limestone. The view represents the side of a manganese pit from twenty to thirty feet in depth. The rock in the center is a protruding mass of St. Clair limestone, showing a surface characteristically rounded off by decay. The rock in the background is the shattered chert which, as the underlying limestone has decayed, has sunk down over the protruding knob, dipping off from it on all sides in the form of a cone. The excavation was made on the apex of this cone and the dip of the chert can be seen on all sides of the pit. At the base of the chert, and occupying the foreground in the drawing, is the manganese-bearing clay. This surrounds the knob of limestone and a shaft is said to have been sunk into it for a depth of over 50 feet below the bottom of the pit.

Figure 10,† on page 195, represents, on a smaller scale, a cross section of the same pit. It is at right angles to the view in the drawing, and therefore, in connection with it, brings out the conical form of the chert. It shows an additional knob of limestone, but otherwise illustrates the same subject.

It is only in a few places in the manganese region that ex-

* This locality is described more fully in chapter X.

† Numerous other figures illustrating the decay of the St. Clair limestone, the formation of ore-bearing clay, and the consequent disturbances in the chert are given in chapters IX and X.



THE GRUBB CUT, BATESVILLE REGION, ARKANSAS.

posures of the disturbed chert can be seen, as the surface is usually covered by loose rock which obscure the dip. But in many openings at the Southern mine, and in a few other places, the faults and steep dips are clearly shown. From the similarity of

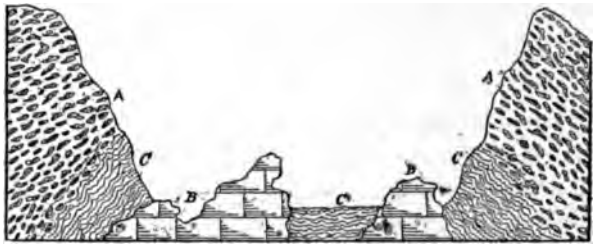


Figure 10. *Section through the Grubb Cut, one mile north of Cushman, showing the decay of the St. Clair limestone, the formation of residual manganese-bearing clay, and the subsidence and tilting of the overlying Boone chert.*

A. Boone chert.
B. St. Clair limestone.
C. Manganese-bearing clay.
Horizontal and vertical scale: 1 inch — 80 feet.

these places to the surrounding chert-covered country, it seems probable that all of the region, where the St. Clair limestone has been leached from under the chert, is affected in the same way.

Most of the topographic inequalities in the barren chert region lying south of the manganese area, however, are formed by the simple process of the erosion of the chert, as can be seen by the horizontal position of the beds where they are exposed in the sides of the ravines. There are no indications of disturbance, and, though the slopes are covered by chert fragments, these are only pieces broken from the exposed edges of the main formation. This is especially true in the southern part of the chert area, where the formation crops out in its full thickness, and the limestone is beneath the drainage level of the country. It is to the north, therefore, in the manganese region proper, where the chert covering is thinner than it is to the south, and where the limestone begins to yield to the dissolving powers of carbonated waters, that the phenomena already described occur.

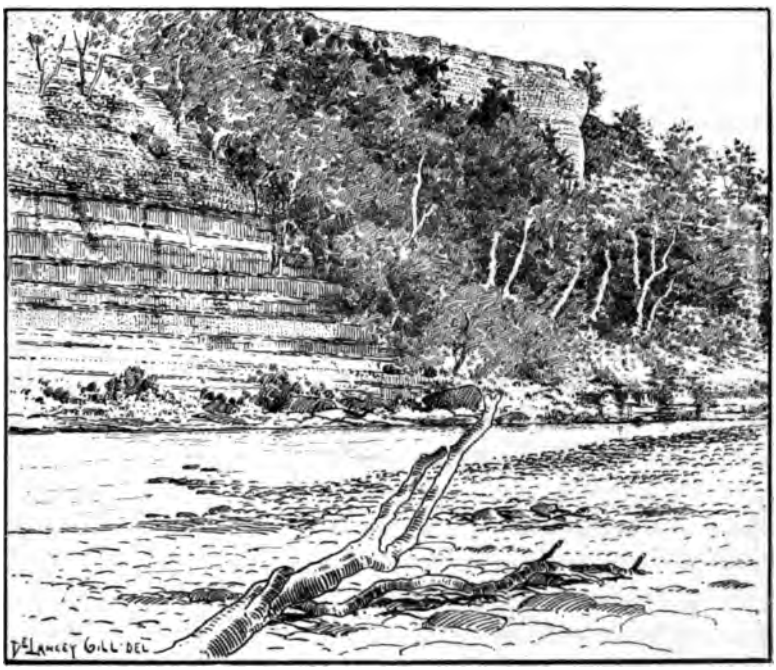
The accompanying drawing, from a photograph, represents

the chert and St. Clair limestone in the bluffs on the east side of Polk Bayou, four miles north of Batesville. The locality is only a short distance north of the most southerly outcrop of the St. Clair limestone, and this formation still retains its full thickness in an undecayed condition. It comprises the lower part of the bluff, reaching from the bed of the bayou in the foreground, up to where the dark line passes along the surface of the rock on the left side of the drawing. Above the St. Clair limestone is the chert formation, dipping gently with the limestone to the south, and showing none of the disturbances seen in the last drawing; the reason being, as just explained, that the limestone has not decayed and therefore the chert has not subsided as it has done at the Grubb Cut. At the Polk Bayou locality, the chert forms a very steep and, at times, perpendicular ledge, frequently protruding in bold, turret-like forms, as seen on the upper right hand side of the drawing. Its weathered surface is markedly contrasted with that of the underlying limestone, by rough, protruding knobs and layers, representing the more resistant parts of the formation.*

MANGANESE IN THE CHERT.

Manganese stain in the chert.— Wherever the chert overlies or is mixed with the manganese-bearing clay, it is almost always more or less stained with manganese, which usually occurs as a thin layer, coating the loose fragments or permeating the cracks of the rock. Such layers are often so numerous that the chert presents a network of intersecting black lines. An examination of the chert formation, where it is solid and overlies the undecomposed limestone, shows that it is free from this stain, but wherever it is broken and overlies the ore-bearing clay, it invariably contains more or less black discoloration. It seems more than likely, therefore, that this manganese did not originally belong in the chert formation, but that it was brought there. It was probably derived in solution from the underlying ore deposit by capillary action and deposited in crevices of the broken

* See Boone chert, chapter VI.



THE BLUFFS OF POLK BAYOU, BATESVILLE REGION, ARKANSAS.

chert. The existence of such crevices would greatly facilitate capillary action, and it is a noticeable fact, that the amount of manganese in the chert increases as the contact with the clay is approached.

In many fragments of chert, the manganese solutions have permeated the entire mass and have changed parts of it into an opaque, black material. These impregnations seem to follow the most pervious portions,* and run into them in the form of "stringers" or irregular masses. Subsequent disintegration has often removed the part that was not impregnated, leaving masses of a highly siliceous manganese ore of a stalactitic, botryoidal or mammillary form.

Manganiferous chert breccia.—A breccia of angular chert fragments, cemented in an earthy, black, manganiferous matrix, is frequently found in the manganese region. This seems to have originated by the imbedding of chert fragments in a dark manganiferous clay, which was subsequently indurated. Very often such a combination seems to have been hardened by the infiltration of surface waters containing manganese in solution. The breccia is always on the surface, or in the upper part of the clay bed; never in situ in the chert, or at any distance from the clay. As in the case of the manganese stain mentioned above, so here, the chert seems to have derived its manganese from the underlying deposit. That this breccia did not originally belong in the chert formation, is proved by the fact that waterworn pebbles, similar to those now seen on the surface, and representing the action of late geologic times (Tertiary or Pleistocene), are frequently cemented in the mass with the angular fragments of chert.† A typical occurrence of the breccia is seen

* It is possible that these pervious portions represent the more calcareous parts of the chert and that the presence of manganese is due to a replacement of carbonate of lime.

† Breccia cemented by manganese oxides and occurring in situ in the country rock are mentioned further on in this volume, in the description of the manganese regions of southwestern Arkansas, Georgia, Nova Scotia and elsewhere.

on the Bruce tract, in the northeastern part of the manganese region.* (See chapter IX).

Altered surface of the manganese deposits.—In many places where the ore deposit is exposed on the tops of the hills, there occurs, resting unconformably upon the surface of the residual clay, a deposit of a brown, sandy clay, from three feet to over ten feet in thickness, containing both rounded and angular fragments of chert and partly disintegrated masses of manganese ore. This deposit is usually somewhat lighter in color and of a more porous nature than the underlying and undisturbed clay. Its sandy consistency has allowed the free percolation of water, and the ore fragments that it encloses have been partly dissolved and honeycombed on the outside, leaving a dull, earthy, porous crust which often contains a kernel of the original hard ore; while below, in the clay deposit proper, the impervious nature of the enveloping material has protected the ore from such decay. In the latter deposit, no pebbles rounded by rolling are ever found. The rounded masses of St. Clair limestone sometimes have this appearance, but, as already shown, their shape is entirely due to the dissolving action of surface water on the rock and not to any process of mechanical wearing. Angular fragments of chert also occur in the upper part of the clay bed proper, but they are the products of the breaking up, in situ, of the chert formation.

The overlying sandy deposit, just described, is the result of the mixing of the top of the underlying ore-bearing clay with surface materials in the form of pebbles and sand. The masses of ore and the angular chert fragments in it have come from the underlying clay, while the rounded pebbles and the sand have come from outside sources.

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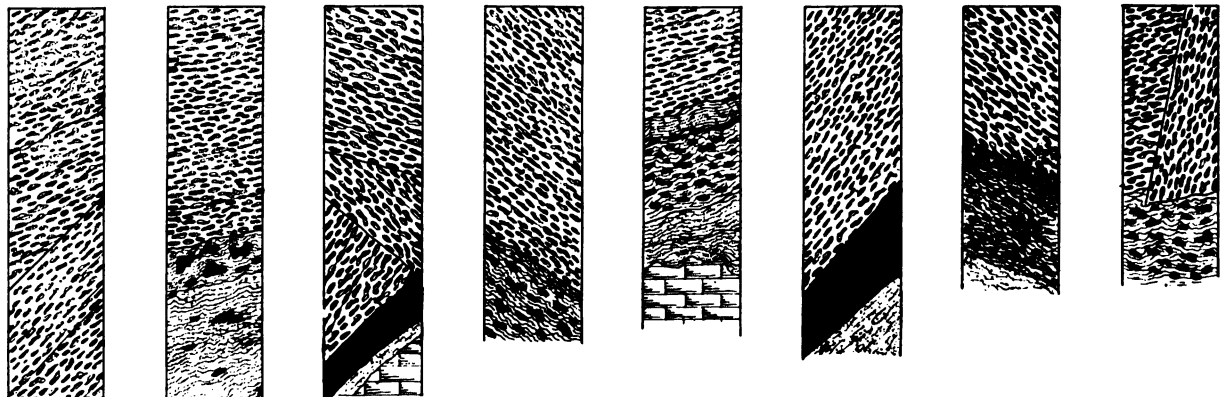
* Iron ore, in the form of brown hematite and of red hematite, occurs in a chert rock in the region bounding the manganese area on the northwest, and in some places the brown hematite composes the cement of a breccia of masses of chert. The iron ore of this region has not been carefully examined, and therefore, no definite statements can be made concerning it, but perhaps, in this case, the ore may belong in the chert and may not have been brought from outside, as in the case of the manganiferous breccia just described.



SECTIONS SHOWING

THE OCCURRENCE OF MANGANESE ORE

IN SHAFTS OF THE SOUTHERN MINE

BOONE CHERT
"OCHRE"
CLAY, RED AND BROWN
CLAY, "BLACK JOINT"
SAND AND SANDY CLAY, "SAND BARS"
MANGANESE ORE
ST CLAIR LIMESTONE

Vertical Scale: 1 inch = 25 feet.

THE OCCURRENCE OF MANGANESE ORE AS ILLUSTRATED AT THE SOUTHERN MINE.*

The columns on the accompanying plate show eight sections through the surface chert and extending into the ore-bearing clay at the Southern mine. They are taken from eight typical shafts on the property, and, in each case, represent the depth to which the shaft was sunk. The vertical scale on which the sections are drawn is 25 feet to the inch, and the shafts vary from 35 to 85 feet in depth. The noticeable features are:

(1) The shattered and faulted condition of the chert, its changing and often steep dips, and its variable thickness. All of these features are due to the decay of the St. Clair limestone and the subsidence of the once horizontal chert, as explained on pages 191–193.

(2) The frequent though not invariable presence of the so-called "ochre" between the base of the chert and the ore-bearing clay. This represents the remains of a former earthy or shaly stratum between the top of the St. Clair limestone and the base of the chert. (See page 175).

(3) The manner of distribution of the ore in the clay, sometimes in loose masses, sometimes in solid bodies.

(4) The existence, in some of the shafts, of masses of St. Clair limestone. These represent parts of the original limestone formation that have as yet escaped decay, and are locally called "gray rock." So far as is known, they exist simply as isolated masses, and not as the bed rock of the clay deposit. The clay often extends far below them. They vary from a few inches to several feet in diameter.

(5) Immediately below the ore-bearing clay, there is frequently a deposit of sand or sandy clay, known as "sand bars." Sometimes it is in a loose, incoherent state, and at other times it is compact and massive. It varies on this property from four to twenty feet in thickness, and averages about eight feet. It

* A detailed description of the Southern mine is given in chapter X. The present mention of it is made for the purpose of illustrating the principles involved in the derivation of the manganese deposits of the Batesville region and described in the preceding pages.

probably represents the partly disintegrated remains of one of the subordinate sandstone beds of the St. Clair limestone, described on pages 179-170. The decomposition of the limestone and its conversion into clay, have left the sandstone stratum, in a more or less disintegrated state, imbedded in the clay. The ore on this property usually occurs immediately above this sandy stratum, though sometimes the latter is struck in the shafts without passing through any ore. This points to a greater continuity of the sandy stratum than of the ore, and such is also the case elsewhere, in places where sandstone beds carrying manganese ore are found in the original limestone. In such places, the ore occurs in disconnected masses throughout the sandstone. Judging from the relative positions of the ore and the "sand bars" at the Southern mine, it appears that the ore in the St. Clair limestone, before it was set free by the decay of that rock, was in a series of lenticular layers and pockets overlying one of the sandstone beds in the limestone; also, judging from the present nearness of the ore to the base of the chert, it appears that both the ore and the sandstone were originally near the top of the St. Clair limestone.

It is generally found that, in sinking through the "sand bars," a body of St. Clair limestone is struck, and therefore the shafts usually stop when the sandy deposits are met. Between the limestone and the sand, there is often a layer of dark brown or black clay, "black joint," varying from a few inches to several feet in thickness. It represents the decomposition product of the surface of the mass of limestone, and similar layers are found elsewhere in the lower part of the ore-bearing deposits.

From a consideration of the above facts, the ideal columnar section on page 201 has been compiled, as showing the probable original condition of the ore deposit when it was interbedded in the St. Clair limestone; while the sections of the shafts show what has taken place by the decomposition of this limestone and its conversion into ore-bearing clay.

It will be observed in the ideal section: that the chert was originally horizontal or nearly so; that its thickness was formerly much greater than it is now, even the thickness given in the

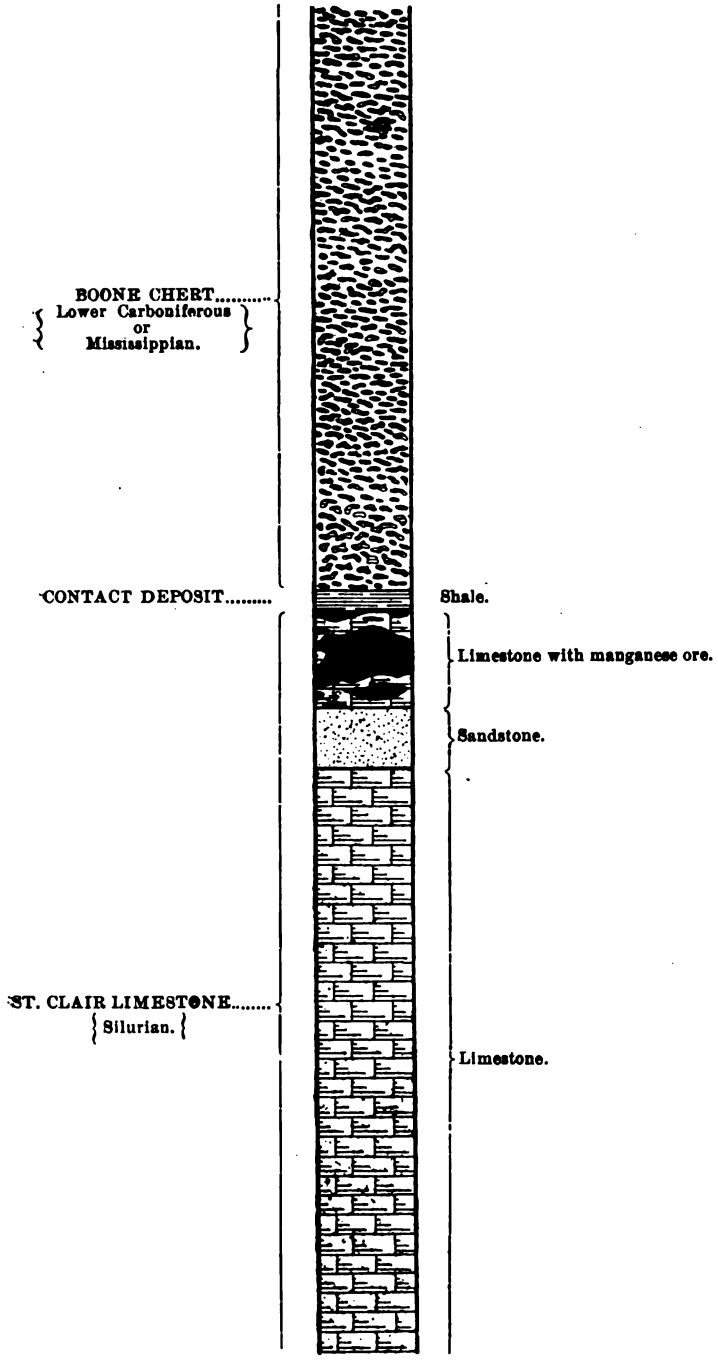


Figure 11. *Ideal section showing the probable condition of the manganese ore at the Southern mine previous to the decay of the St. Clair limestone.* Scale: 1 inch=25 feet.

column being probably not much, if any, over half the original thickness of the formation; that at the base of the chert was a shaly deposit from one to over three feet in thickness, occupying the line of contact of the chert and the limestone and representing the original condition of the present deposit known as "ochre" at the base of the chert and above the ore-bearing clay; that below the shale was the St. Clair limestone, containing irregular masses of ore in its upper part; that immediately below the ore-bearing part of the St. Clair limestone was a bed of sandstone representing the original condition of the "sand bars" now found at the base of the ore; that the sandstone was directly underlain by the remaining part of the St. Clair limestone. The portion of the St. Clair limestone shown in the column represents only a part, probably not much, if any, over half of the original thickness of the formation, and almost the whole of this total thickness has now been reduced to residual clay.

It may be stated here, that the base of the clay at the Southern mine has not been reached in any of the shafts yet sunk, and therefore the existence of ore at the bottom of the deposit has not yet been proved. If future tests should show it to occur at the base of the deposit, it must also have existed in a similar position at the base of the original limestone, as well as in the upper part of the limestone just described. Moreover, it is not yet known whether the base of the St. Clair limestone at this mine has decayed. As shown in the section of the shafts just described, masses of that rock are of frequent occurrence, but since most of the shafts, when they meet large bodies of it, are not sunk any deeper, the question as to whether the latter represent isolated masses or peaks rising up from the bed rock below is, in some cases, uncertain. Many of them have been proved to be simply isolated bodies imbedded in the clay. It has not yet been practically demonstrated that any of them are connected with a main body of St. Clair limestone ("gray rock") below, but it is not impossible that some of them found at considerable depths may prove to be so connected, and that isolated areas of the original limestone may still exist in situ at the base of the clay. This is rendered still more probable by the fact that con-

siderable thicknesses of undecayed limestone occur to the north, south, east, and west of the mine. That a larger part of the rock, however, has decayed, is proved by the depth to which some of the shafts have gone in the clay, by the absence of outcrops of St. Clair limestone anywhere on the hill, and by the disturbed condition of the chert, resulting from its subsidence in consequence of the removal of the underlying limestone.*

GENERAL SUMMARY OF THE BATESVILLE REGION.

It has been the object of the last three chapters to explain the historic and geologic features of the Batesville region, and the nature, derivation and mode of occurrence of the manganese ores. The facts brought out and the conclusions arrived at may be briefly summarized as follows:

Location.—The region is in the northeastern part of the state, in the valley of the White River and above the confluence of the latter with the Black River. The region includes parts of Independence, Izard and Stone counties, comprising an area of about 122 square miles, in which manganese ores occur at greater or less intervals.

History.—Manganese mining was begun in the Batesville region between 1850 and 1852 by Col. Matt. Martin, but no extensive work was done until 1881 when Mr. E. H. Woodward commenced mining. In 1885 the Keystone Manganese and Iron Company began operations at the Southern mine, and at once became the largest producers of manganese in the region. At present this company and John B. Skinner and Company are the principal active operators. Between 30,000 and 35,000 tons of manganese ore were shipped from the Batesville region between 1850 and 1890, though almost all of this quantity was shipped between 1881 and 1890 inclusive.

Topography.—The prominent topographic features of the Batesville region and the surrounding country are the Boston Mountains south of the White River, the chert hills north of the river, the rolling limestone and sandstone country still further

* For further discussion of this subject, see the description of the Southern mine in chapter X.

north, and the low, river bottom area which cuts off the mountainous and hilly country on the east.

Structure.—The general structure of the Batesville manganese region is that of a broad monocline dipping to the south and southwest at low angles, and finally disappearing under the much more disturbed Carboniferous rocks of the central part of the state. Sometimes the rocks are horizontal or dip at a fraction of a degree, but at intervals they dip at angles of from 5° to 20°; and the general monoclinal structure of the country may be said to be made up of gently sloping or even horizontal areas connected by local areas with steeper dips. Faults with throws of from 50 to over 200 feet sometimes occur, and in certain places have an important bearing on the topography of the country.

Age of the rocks.—The rocks of the region are of Silurian and Carboniferous ages. The lowermost Silurian rocks belong to the Calciferous group. Above them is the Izard limestone overlain in turn by the St. Clair limestone. The latter formation represents the uppermost member of the Silurian in the region, and has been determined by Professor Henry S. Williams as belonging to a horizon intermediate between the Trenton and Niagara groups. The St. Clair limestone is the source of the manganese ores.

The Carboniferous rocks include the Mississippian, or Lower Carboniferous, and the Millstone grit. The Mississippian of southern Missouri and northern Arkansas has been divided by Professor Williams into three groups, which in ascending order are: the Chouteau, Osage, and Genevieve or Boston. The Chouteau includes the "Lithographic," "Vermicular," and "Chouteau" of the Missouri classification, and, so far as known, is absent in the region in question. The Osage group, which includes the "Burlington," and "Keokuk" groups, is represented in the Batesville region by the Boone chert, the Fayettville shale, and Batesville sandstone. The Genevieve or Boston group is represented by a series of limestones, shales, and sandstones, reaching from the top of the Batesville sandstone to the base of the Millstone grit. The

presence or absence of anything representing the Devonian age is in doubt. The contact of the Silurian and Carboniferous is generally represented by sandy or shaly strata, or both, varying from a few inches to 30 or 40 feet in thickness. In one place a material, which, under the microscope, partakes of the nature of volcanic ash, is found at the parting of the two horizons, in a bed from six to fifteen inches in thickness.

The Paleozoic area is cut off abruptly on the east by the Tertiary, Pleistocene, and Recent deposits of the Mississippi Valley.

The manganese ores.—The manganese ores of the Batesville region represent oxides of the metal. They are usually in the forms of psilomelane or braunite. Pyrolusite is found in small quantities, and wad occurs in some places. The sample of braunite described by William Elderhorst, of the Owen Survey, in 1858, and that described in the present report, show certain noticeable variations in the contents of silica similar to the variations in the braunite of Elgersburg, Germany, analyzed by Turner and by Rammelsberg; the Arkansas specimen, analyzed by Elderhorst, and the Elgersburg specimen analyzed by Rammelsberg, contained 9.968 and 8.63 per cent of silica respectively, while the Arkansas specimen analyzed by the present Survey, and the Elgersburg specimen analyzed by Turner, showed 0.18 per cent of silica and no silica respectively.

The commercial value of the better grades of the Batesville ores, as shown by chemical analyses of car-load shipments, is equal, for the manufacture of spiegeleisen and ferromanganese, to the best at present mined in the United States. The strong points of the ores are their high per cent of manganese and their low per cent of silica. Their weak point is their occasional high per cent of phosphorus. This ingredient, however, is only occasionally in injurious quantities, and large amounts of ore are mined which contain a very low per cent of it.

Derivation of the manganese deposits.—The manganese ores

occur in masses and nodules of various sizes in a red clay, and both they and the clay are the residual products of the decomposition of the St. Clair limestone ("gray rock.") The latter formation is a crystalline rock, sometimes containing interbedded lenticular strata of sandstone or of shaly materials. The ore occurs in various positions from the base to the top of the limestone, either with or without the sandy and shaly accompaniments. It exists in flat layers following lines of bedding, in irregular masses, in small grains, or in a finely disseminated state, giving the rock a chocolate-brown color. The ore is only of local occurrence in the rock and is often absent over considerable areas. Therefore the ore-bearing clay is also of only local occurrence. In a similar manner, the Batesville region, considered as a whole, represents an isolated abnormal accumulation of manganese in the St. Clair limestone. This formation is characterized by small quantities of manganese throughout a large area of exposure in northern Arkansas, but, so far as known, it exists in large quantities only in the Batesville region. The limestone is found in all stages of decay, sometimes containing only small pockets of the residual materials on its partially decomposed surface, at other times completely decayed, leaving only the residual clay with greater or less quantities of ore.

The ore existed in the limestone, at least in the surface exposures of that rock, in the oxide form, just as it now occurs in the clay.* Possibly below the drainage level of the country, it may be in the form of carbonate, in which form, probably, it was originally deposited; but this has not yet been proved, and it is not impossible that it may exist in the oxide form throughout the whole extent of the limestone.

Chemical relation of the St. Clair limestone and the manganese-bearing clay.—The analyses of the St. Clair limestone and the residual clay show them both to contain, usually, different proportions of the same materials, though sometimes the carbonate of lime of the limestone has been completely leached from the residual clay; while the less soluble si-

* See page 167 for details.

liceous and argillaceous materials, and some metallic oxides have been proportionally increased in their percentages. Almost all the ingredients, however, have suffered more or less loss, and a table of the per cent saved and the per cent lost of each constituent, calculated on the basis of the assumed insolubility of the silica, is given on page 182.

Nature of the manganese deposits. — The ore-bearing clay is a plastic material generally of red, chocolate-brown or yellow color, and sometimes of a deep purplish-red. It contains the manganese ore in the same or nearly the same forms as the original limestone contained it, that is, in flat layers, irregular masses, grains, or as a finely disseminated dark chocolate-brown coloring material. Very often the larger masses of ore have been broken in their change of position from the limestone to the clay, and now exist as irregular, angular fragments. The masses of ore occur in pockets in the clay, in quantities varying from a few pounds to over five hundred tons.

The ore-bearing clay contains numerous more or less rounded masses of the St. Clair limestone, which represent the parts of that formation that have so far escaped decay. They have not been transported from without into their present position, as is often supposed, but are the remains of the decomposition of the limestone in situ.

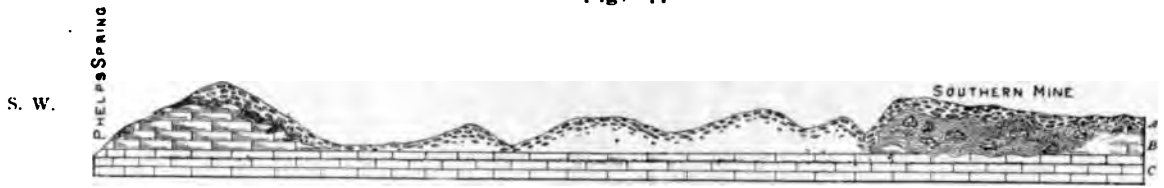
The chert capping of the manganese deposits.—The St. Clair limestone, before it decayed, was overlain by a chert formation (the Boone chert) sometimes over two hundred feet thick. The process of decay has gone on underneath this covering, and the chert has been let down on the residual clay and ore in a broken mass, which, though partially decayed itself, often retains 30 to 60 feet of its original thickness, even after all the underlying limestone has been decomposed. By this undermining, the chert has, in some places, suffered a slow subsidence of fifty to over a hundred feet and has been greatly shattered, broken, and curved, in a manner, in some respects, not unlike folding by lateral pressure. The unequal decay of the St. Clair limestone has

caused an unequal subsidence in the chert, and the results are small shattered anticlines and synclines, depending for their form and extent on the contour of the underlying surface of the limestone.

Sometimes manganese in solution has been carried up into the cracks of the broken chert by capillary action and deposited in the form of oxide in thin black layers, nests, or films throughout the rock. In places also the base of the broken chert has become mixed with a highly manganiferous residual clay, which has filled the cracks and become indurated, forming a chert breccia. Occasionally rounded pebbles are enclosed in the breccia.

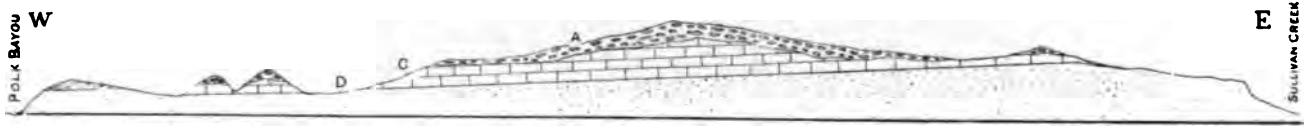
The example of the Southern mine.—The processes by which the manganese ores have been derived from the St. Clair limestone are well illustrated at the Southern mine. The relation of the ore deposit as it now exists to its former condition in the limestone, can be traced out, and the effects of the transition on the ore bodies and on the accompanying materials, as well as on the overlying chert, are apparent. (See pages 199–203.)

Fig. 1.



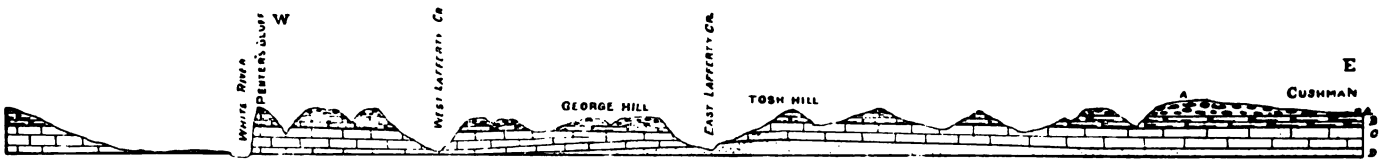
Northeast-southwest section from the Grubb Cut through the Southern Hill to Phelps Spring, showing the unequal decay of the St. Clair Limestone. Horizontal scale: 1 inch 800 feet. Vertical scale: 1 inch 400 feet. (See page 266.)

Fig. 2.



East-west section across Polk Bayou and Sullivan Creek ridge in township 15 N., 6 W., Secs. 3—, 32 *and* 33. Horizontal scale: 1 inch ⅓ mile. Vertical scale: 1 inch 800 feet. (See page 24?.)

Fig. 3.



East-west section across the Lafferty Creek basin from Cushman to the White River. Horizontal scale: 1 inch 1 mile. Vertical scale: 1 inch 2000 feet. See page 257.)

A. Boone Chert. B. St. Clair limestone. C. Izard limestone. D. Saccharoidal sandstone.

SECTIONS IN THE BATESVILLE REGION OF ARKANSAS.

CHAPTER IX.

THE BATESVILLE REGION OF ARKANSAS—*Continued.*

EXPLANATION OF THE MAP.

Natural divisions of the region.—It will be seen on the map that the Batesville manganese region is well watered by numerous springs and small streams. The largest of the streams rise in the southern slope of the divide between the waters of the White River and those of the Strawberry River and flow south, through the manganese area and the rugged chert barrens, eventually emptying their waters into the White River. This river itself passes through the western portion of the manganese country, but to the east, it bears off from three to fifteen miles south of that area.

The region where the ores of manganese occur in quantities, may be divided into two principal drainage basins: the Polk Bayou* basin with its tributaries, to the east, and the Lafferty Creek basin with its tributaries, to the west. The towns of Cushman and Barren Fork stand on the divide between these drainage areas. To the east of them the waters drain into Polk Bayou, to the west into Lafferty Creek.

The Polk Bayou basin, as will be seen on the map, is the

* The term "bayou," as used to designate the stream known as Polk Bayou is a misnomer. A bayou, properly speaking, is a sluggish water course passing through a low, flat, or marshy country, and is commonly applied throughout the southern part of the United States to "the outlet of a lake, or one of the several outlets of a river through its delta." (Century Dictionary.). Polk Bayou, on the other hand, is a rapid mountain stream, partaking of none of the sluggish characteristics of a true bayou. In wet weather it is frequently a torrent, sweeping before it everything that obstructs its course in the narrow ravine through which it flows; while the banks of sand and pebbles, as well as the many uprooted trees along its course, attest to the misapplication of the term "bayou." A similar misuse of the term is noticeable in the names of many other streams in the mountainous region of northern Arkansas, and has frequently led those unacquainted with the state to imagine that it is all low and swampy.

larger of the two and drains over half the manganese region. It receives the waters of many tributary basins, the principal ones being Barren Fork, Prairie, Sullivan, Cave and Miller Creeks. It empties into the White River at Batesville. The Lafferty Creek basin includes the region of East, Middle, and West Lafferty Creeks, Turner Creek, Blowing Cave Creek, and other small streams. It empties into the White River a mile below Penter's Bluff and fifteen miles northwest of Batesville. Most of the workable manganese, as yet discovered in the region in question, is included in these two drainage areas.

A view from the high hills about Cushman discloses the most striking features of the country: to the east and north is the rolling country of the Polk Bayou basin and its tributaries, studded with chert-capped hills. Beyond, to the east, the chert hills rise up in the divide of Cave Creek and Miller Creek, and the head waters of Dota Creek, forming a natural boundary to manganese region. To the west is the broken country in the valley of the Lafferty Creeks, hemmed in beyond by Lee's Mountain and the rugged Wilson Hills. To the south are the chert highlands overgrown with a forest of stunted oak and hickory, and in the background are the Boston Mountains following the course of the White River to the east and west.

Effect of erosion.—As a result of the gentle southerly dip of the region, lower strata are successively exposed on the surface in going north. On this fact depends the existence of the manganese in its present form, since, as a result of the dip, the St. Clair limestone has been exposed on the surface between the overlying chert on the south and the underlying Izard limestone on the north. This has allowed the atmospheric agencies to attack the rock, disintegrate it, and leave the residual clay and manganese ore as described in chapter VIII. To the south of the region of its exposure, the St. Clair limestone dips in an entirely undecomposed state under the protecting cap of chert and the rocks of the Boston Mountain region.

As another result of the general southerly dip, the country in which the various formations are exposed would, were it not for erosion, occupy regular and well defined belts, all

running parallel to each other in a general east-west or south-east-northwest direction; but, though an examination of the map will show that the general strike of the belt of country in which any given rock is found is in these directions, yet the action of the atmospheric agencies has greatly altered the regular trend of the rocks over limited areas. Numerous creeks have cut through the rocks that once covered the surface and have exposed the underlying beds, which, had it not been for this cutting, would not have been seen until the general southerly dip brought them to the surface probably several miles farther north. Lafferty Creek, for example, has cut down through the chert and the underlying rocks, exposing them successively in its bluffs. Its numerous tributaries have cut down in a similar manner, though the smaller streams had not the power to cut so deeply, and therefore have exposed less of the underlying rocks. In the same way, Polk Bayou and Sullivan, Cave, and Prairie Creeks, as well as all the other streams seen on the map, have cut down into the rocks underlying the chert and have exposed them in belts along their courses.

As a result of this erosion, high divides, heavily capped with chert and exposing the St. Clair limestone and other lower formations on their slopes, exist between creeks. Such a divide occurs between the lower parts of East and West Lafferty Creeks. As will be seen on the map, the top and central part of the divide, just above the confluence of these creeks, are covered by chert. Descending the divide on either side, the St. Clair limestone is next met with, and still lower the Izard limestone appears, while the bed of the creek, in some places, is composed of the underlying sandstone. It will be seen that several small creeks running into West Lafferty rise on this divide, and they also have cut through the chert and into the lower beds. On the bluffs bounding either of the creeks on the opposite side from the divide, the same series of rocks is seen, and when the chert on the summit is reached, this rock continues to cover the surrounding highland until another creek is met.

The divide between the head waters of Cave and Miller

Creeks is heavily covered with chert, and in the bluffs of both streams the St. Clair limestone is exposed. Neither of the creeks, in this region of their head waters, has yet cut down to the Izard limestone, though that rock underlies the lower part of the Cave Creek basin.

On the southern part of the divide between Sullivan Creek and Polk Bayou, the chert and St. Clair limestone have been completely removed and hence the Izard limestone occupies the summit. On the slopes toward either creek, the underlying sandstone appears.

The divides of streams are often cut across by deep ravines, in which creeks rise and run in both directions. As a result, there often occur isolated hills, or outliers,* capped with chert and showing the underlying rocks on all sides. A typical example of this is seen in Lee's Mountain, in the northwest part of township 15 N., range 8 W. This mountain once formed a portion of the chert area to the south known as the Wilson Hills which constitute a part of the divide between West Lafferty Creek on the east and Rocky Bayou† on the west. Two small creeks head in the Izard limestone just south of Lee's Mountain, one running southeast into West Lafferty Creek and one running west into Rocky Bayou. These creeks doubtless once had their headwaters in the chert-capped region which formerly connected Lee's Mountain with the Wilson Hills; but they gradually cut farther and farther back on the divide, removing successively the chert and the underlying St. Clair limestone, until finally the Izard limestone was exposed at their headwaters. As a result, the chert and St. Clair limestone in Lee's Mount-

* The term *outlier* is used here to indicate an area of a given rock separated, as a result of erosion, by a greater or less distance from the main outcrop of the same rock and surrounded by an area of the underlying rock or rocks. As thus defined, an outlier of any given rock may contain on its surface subordinate outliers of one or more of the overlying rocks, as explained in the following pages. This definition of an outlier is only intended to apply to a region like the one in question, where the rocks are horizontal or have only a slight dip. In regions where the rocks are more disturbed a more modified definition would be needed.

† This stream is not shown on the map, but is about six miles west of West Lafferty Creek.

ain have been separated from the region to the south, and represent an outlier of these rocks surrounded on all sides by Izard limestone.

This formation of outliers, as will be seen on the map, is one of the most characteristic features of the manganese region, and many of the ore deposits are situated on them. In most of the outliers, however, the St. Clair limestone has been entirely decomposed and the chert overlies the surface of the Izard limestone, as explained on page 177. Consequently outliers of chert are often surrounded by the Izard limestone; and outliers of this limestone, capped by chert, are frequently surrounded by the underlying sandstone. These are the most common forms of outliers in the region, and frequently single areas of Izard limestone have several isolated areas of chert scattered over their surface. The manganese and its associated clay lie between the chert and the limestone.

Hence it will be seen that surface agencies have greatly altered the configuration of the country, but a study of the mode of procedure and the results of this erosion, will give a clear insight into the present structure of the region and greatly facilitate the intelligent mining of its ores.

Extent of the Boone chert.—In the country north of the White River, east and west of Batesville, the chert appears from beneath the Batesville sandstone and the underlying shale, and forms a prominent feature of the country. It consists of a barren region of rugged hills, covered by loose, angular fragments of chert and deeply cut by the narrow ravines of many streams, though occasionally its monotony is broken by a more gently sloping creek bottom, in which the farmer has found small areas of tillable land. This belt of country varies from three to seven miles in width, and marks the southern limit of the manganese ores. On the east it is abruptly cut off by the low country of the Black River bottom. Thence it runs west through the lower parts of Polk Bayou and Lafferty Creek basins, and crosses the White River fifteen miles northwest of Batesville. At this point it rises up from the flat river bottom in bluffs of from

50 to over 100 feet in height, presenting a rough, eroded surface of interbedded seams of limestone and chert, dipping off gently to the south and southeast and finally dissappearing under the Batesville sandstone. On the west side of the White River, in Stone county, the chert belt bears off to the northwest and forms the same character of country as that already described.

North of this rugged area, the chert still continues, but it no longer forms the only rock of the region. It now occurs as the capping of the hills and ridges, in the sides of which the St. Clair limestone and underlying beds are exposed.

Extent of the St. Clair limestone.—The St. Clair limestone first appears on the south in its full thickness and in an entirely undecomposed state; but a short distance to the north, the protecting cover of chert becomes thinner, the limestone has begun to succumb to atmospheric agencies, and its residual clay and manganese ore have collected in hollows on its decayed slopes. In many places the bed has been entirely decomposed into its residual products, and only scattered outcrops of the original rock are seen along the line where it doubtless once appeared continuously. These intermittent outcrops are probably often connected by areas of the same limestone, but the line joining them would run under the capping of chert, and sometimes far back into the area of that rock. Hence, as is seen on the map, though the southerly outcrops of the St. Clair limestone are often continuous for considerable distances, the northerly outcrops are broken, and are represented by isolated areas between the chert and Izard limestone. Between these areas of St. Clair limestone the altitude of the hills is generally much lower than where that bed appears, since the chert has subsided a vertical distance proportional to the amount of limestone that has been dissolved. (See page 192–193.)

Still further north, the St. Clair limestone has been entirely decomposed, with the exception of a few scattered knobs, and the residual clay lies on the decayed surface of the

underlying Izard limestone. Part of the chert still remains even in this Izard limestone area, and though its thickness has generally been greatly diminished, it often forms prominent rocky knobs on isolated hills and ridges.

Extent of the Izard limestone.—The region of chert-capped hills with Izard limestone and residual clay below, is characteristic and comprises the larger part of the manganese area. Sometimes the loose, broken chert has rolled down and covered the Izard limestone slopes, and has come into direct contact with the still lower sandstone. This occurrence is shown on the map in several of the outliers in township 15 N. Gradually, to the north, the chert-capped hills of limestone become fewer and separated by larger and larger areas of the underlying rocks, until, eventually, they dissappear in the region of lower Silurian sandstones and magnesian limestones that bound the manganese country on the north.

METHOD OF DESCRIPTION OF THE BATESVILLE REGION.

It will be seen, from what has been said, that surface erosion in the manganese region has divided the ore-bearing localities into different parts, separated by barren areas and depending for their existence and their form on the amount of denudation of each drainage system. Therefore, in the following detailed description of the region, the different localities are treated under the headings of these natural divisions. The plan adopted is to divide the region into two main areas, the Polk Bayou basin and the Lafferty Creek basin. Under these headings are described not only the localities in the immediate valleys of these streams, but also the regions of all their tributaries. As thus defined, the two basins include the whole of the manganese region with the exception of a corner of Stone county, which will be treated separately. These divisions are not made with any intention of distinguishing, in any way, between the character of ore deposits in different parts of the region, but simply for convenience in description, it being considered better to describe

the region according to its natural divisions than by artificial areas, such as counties and townships. Under each property, however, the locality according to the land surveys will be given.

It has been shown in the previous chapter that a knowledge of the origin of the ores is absolutely necessary for the intelligent prospecting and successful mining of manganese in the Batesville region. Without such a knowledge, any success is largely a matter of luck and cannot be ascribed to any rational judgment of the value of the locality. Many failures heretofore have doubtless been due to a lack of this knowledge, and though long experience gives the miner ability to judge, to a certain extent, of the good or bad prospects of a property, yet without an understanding of the cause of the indications on which he bases his opinion, he is apt to make most serious blunders. In any region such a knowledge is of value to the miner, but it is especially so in the case of the Batesville region, where the question of the source of the ore is at the foundation of the whole matter of successful mining. Consequently the following detailed description is based on the process of the derivation of the ores from the limestone, and, in order that it may be properly comprehended, it is necessary to understand the facts explained and summarized in chapter VIII.

POLK BAYOU BASIN—*General features.*

The name Polk Bayou basin is used here to include the eastern part of the Batesville manganese region, as distinguished from the western part, or Lafferty Creek basin.

Polk Bayou rises in the southeastern part of Izard county and flows thence south through Independence county, emptying into the White River at Batesville. It receives many tributaries the most important of which are Barren Fork, Prairie, Sullivan, Cave and Miller Creeks.

POLK BAYOU BASIN—*Lower part.*

General features.—Ascending Polk Bayou from Batesville, an area of Batesville sandstone is passed over for almost two

miles north of the town, when, as the result of a fault crossing the Bayou in a general east and west, or northeast and southwest direction, the chert suddenly rises up in steep bluffs, reaching a hundred feet and more above the creek. This area marks the southern limit of the chert barrens that bound the manganese region on the south. The fault has a throw of over a hundred feet and represents the more southerly of the two faults illustrated in figure 1, page 111.

Less than a mile further up the bayou, the first exposure of the St. Clair limestone appears. This occurs in the extreme northeast corner of section 5, township 13 N., range 6 W., and on the east side of the bayou, just before the road going north from Batesville crosses it for the first time. A second fault* of over 65 feet, striking in a general east and west or northeast and southwest direction, occurs at this point, and, as a result, over a hundred feet of the St. Clair limestone are exposed in the lower parts of the hills to the north of the road. The nature of the fault and its effect are shown in figure 1, page 111. The road in question passes down the hollow occupying the line of the more northerly of the two faults represented in the figure.

The limestone is of a light gray color, though darker parts occur in the small exposures to the south of the road. No manganese is seen in it. It is still in its unaltered condition, not having yet been affected by the dissolving action of surface waters. The Boone chert overlies it in a ledge one hundred and eight feet thick, in which not only the main chert bed is seen, but also the interstratified layers of chert and limestone which lie at the base of the latter. The chert has an abnormal dip of 1° to 2° N. 45° E.

The John B. Skinner tract.—The John B. Skinner tract is in 14 N., 6 W., section 33, the north half. This property is situated near the headwaters of a ravine, tributary to Polk Bayou. By reference to the map, it will be seen that the creek has cut through the chert and exposed the St. Clair limestone in the bluffs. This has allowed the surface waters to attack the limestone and the resulting accumulation of clay is shown in the ac-

* The nature and extension of this faulted area are more fully discussed on pages 110-112.

companying figure 12. The rock has changed from the light color seen a mile to the southwest, and is a dark chocolate-brown or almost black color, due to the presence of a dark manganiferous clay throughout the rock. Separate masses and layers of ore also occur in the rock, varying from one to three inches or more in thickness. The heavy capping of chert has protected the main part of the limestone which, back in the hill, still remains undecomposed; but on the sides of the ravines, where

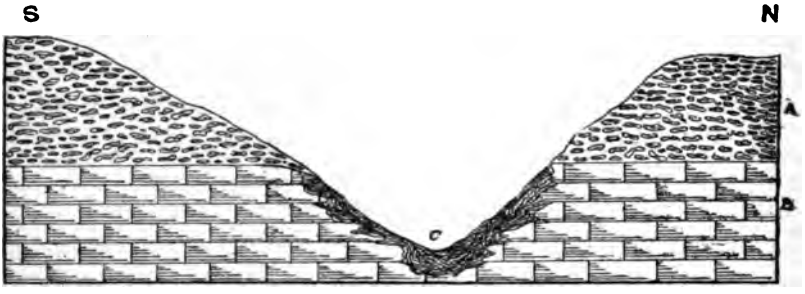


Figure 12. *Section across the Skinner tract showing the formation of manganese-bearing clay on the decayed surface of the St. Clair limestone.*

A. Boone chert.

B. St. Clair limestone.

C. Manganese-bearing clay.

Horizontal scale: one inch — 400 feet. Vertical scale: one inch = 150 feet.

it is exposed, it has been attacked by surface waters, the carbonate of lime carried away in solution and the clay and ore, which were originally disseminated through the rock, have collected as a residual product in the bottom of the ravine, and in the hollows on the decaying slopes of the limestone. Numerous openings made along the slopes of the ravine expose the residual clay and its associated ore.

The clay is of a dark chocolate or red color and contains fragments of ore of various sizes, from one pound to several hundred pounds in weight, as well as masses of chert that have rolled from above. Frequently the separate masses of ore still preserve the flat shape that they had in the St. Clair limestone. In the various diggings, the knobs on the decayed surface of the limestone can be seen projecting into the clay. Pockets of ore in such a deposit as this, are not so numerous as if more of the limestone had decayed, since the clay is directly dependent for its

ore on that in the limestone, and, except where it is freed from that rock, it cannot be mined at a profit.

The chert has a thickness of a hundred and ten feet and comes in sharp contact with the underlying limestone. Only the upper seventy-five feet of the latter are exposed, the rest of it being under the drainage level of the country. The rocks lie almost horizontally.

The following analyses represent the composition of two car-loads of manganese ore from this property. The ore was analyzed by the North Chicago Rolling Mill Company:

Analyses of manganese ore from the Skinner tract.

Manganese.....	38.30	39.35
Iron.....	8.45	5.30
Silica	.....	.....
Phosphorus.....	0.380	0.217

The Cason tract.—The Cason tract is in 14 N., 6 W., section 34, the southwest quarter, and is situated about a mile southeast of the Skinner tract. It belongs to the Keystone Manganese and Iron Company, and is one of the rare cases where the ore is found in large quantities in association with slaty or sandy layers interbedded in the limestone. It is unusual in its occurrence and differs from any other locality in the Batesville region except the O'Flinn place, to be mentioned hereafter. Sometimes the ore is in lenticular layers varying from an eighth of an inch to three inches in thickness, and interstratified with an indurated red clay of a slaty structure. Generally, however, the ore occurs in the shape of flat, lenticular concretions, from a quarter of an inch to one inch in diameter, locally known as "button ore". They have a concentric structure, are dull black on the outside and bright on the inside, and are imbedded in a red or brown, fine grained, and more or less calcareous sandstone. Sometimes, also, they are in the same slaty rock mentioned above, and sometimes in a brown, coarsely crystalline limestone, the latter probably representing a part of the fine grained sandstone bed.

The thickness of this deposit cannot be seen, as only the eroded surface is exposed, but it is probable that the slaty, sandy

and calcareous layers mentioned above, represent a series of successive strata. The deposit underlies an area of about forty acres of the bottom of a hollow, in which a small tributary of Miller Creek rises. It is distinctly stratified in undulating lines and dips at about 2° to the southeast. An old prospect pit is said to have been sunk into the deposit for 20 feet without reaching the bottom. This is now almost entirely filled up, so that very little can be seen of the nature of the materials it passed through. On the northwest side of the deposit a high ridge rises up abruptly, reaching from a hundred and thirty to a hundred and fifty feet above the manganese-bearing bed. It is capped by thirty to fifty feet of chert, and beneath this is a thickness of from a hundred to a hundred and ten feet of St. Clair limestone of a gray or light pink color. At the foot of the hills, the ore-bearing stratum runs under the limestone, and it probably occupies a position at or near the base of that formation.

To the southeast of the manganese deposit, is a low, rolling area, having the characteristic topography of the Batesville sandstone and underlain by that rock. In some places the outcrop of the Batesville sandstone comes within three hundred yards of the foot of the limestone hills. The rocks are all either horizontal or dip at angles of from 1° to 2° to the southeast.* The Batesville sandstone normally belongs in a position above the limestone and chert, yet here it is found at from a hundred and fifty to two hundred feet below it. This occurrence has been brought about by a fault of over 200 feet and probably as much as 250 feet. It strikes in a northeast and southwest direction, and is simply a local development of a line of weakness that runs east and west through the region† and already described where it crosses Polk Bayou. (See page 217.)

The ore on this property occurs in considerable quantities, but so far it has been found to be unmarketable on account of its high percentage of phosphorus. The amount of this ingredient is variable, sometimes being under the maximum

* In one place a local disturbance of 15° was observed in the chert.

† This subject is further discussed on pages 110-112.

allowed, but generally, so far as tested, going above it, and at times amounting to from 2 to almost 4 per cent. If a market is ever opened for high-phosphorus manganese ores, or a method devised to purify them, the Cason property can be made of value.

The deposit, however, has not been thoroughly explored, and it has not yet been proved that all the ore in it is too high in phosphorus to allow it to be marketed. In fact, the investigations of the Survey have shown that, though part of the ore is high in phosphorus, some of it, at least, is comparatively low. How much of the ore is of the pure kind, however, and how much is too high in phosphorus to be of value is a matter that must be determined by a much more extended series of analyses than the Survey has had time to make. Two analyses made by the chemist of the Survey are given below. The first represents a high-phosphorus ore, the second a low-phosphorus ore:

Analyses of manganese ore from the Cason tract.

Manganese	34.64	50.41
Iron	4.88	7.56
Silica	25.65	12.67
Phosphorus	0.58	0.06
Alumina	3.79	1.87
Lime	5.13	2.09

The first analysis shows a poor ore, it being low in manganese and high in phosphorus and silica; but the second analysis shows an ore of excellent quality in every respect except a slight excess of silica. This, however, is not in sufficient quantities to prevent the ore from finding a ready market, especially in view of its high percentage of manganese and its low phosphorus. This sample represents the "button ore" just mentioned, while the first sample was the more earthy ore found in lenticular layers. The sample of "button ore" analyzed was carefully separated from the sandy material adhering to it, and this fact may partially account for the good analysis obtained. Analyses of the ore and enclosing sandstone together have shown the presence, in certain cases, of 3 to 4 per cent of phosphorus, and some analyses of the buttons alone have shown over 1 per cent. Hence,

sometimes at least, the enclosing rock contains more phosphorus than the ore, while the ore alone is sometimes low enough in phosphorus to allow it to be marketed and sometimes is too high. A series of analyses of samples properly selected from different parts of the property and at different depths in the deposit, should be made to determine whether any large part of the ore could be used, and if so, it would be an easy matter to separate it from the enclosing material. The buttons occur in large quantities through the sandstone and limestone layers, and, by a simple process of crushing and washing, or crushing without washing, they could be cheaply freed from the rock.

Comparisons.—It will be seen that at the John B. Skinner tract and at the Cason tract, the two principal modes of occurrence of the manganese ore in the Batesville region are illustrated. The Skinner tract represents the ordinary occurrence of ore in clay derived from the decay of the St. Clair limestone; the Cason tract represents the much rarer occurrence of manganese associated with lenticular beds of argillaceous and sandy materials interstratified in the limestone. At the former place, the limestone has already begun to give way to the action of weathering and has given rise to manganese-bearing beds of residual clay, from which the ore mined has been taken. At the Cason place the more stable materials that carry the manganese have, so far, resisted weathering, and this is one of the few places, if not the only one, in the Batesville manganese region where the ore, if its quality warranted it, could be mined at a profit in the original rock.

Bluffs of Polk Bayou.—Ascending Polk Bayou from the Skinner property, the St. Clair limestone is exposed on both sides of the creek, in the lower parts of high bluffs rising steeply or almost perpendicularly for from two hundred to four hundred feet and more, and capped by the chert formation.

Back from these cliffs, is the highland country already described, underlain by chert and strewn with loose fragments of the same material. The rocks are either horizontal or dip at 1° to 3° to the south, and the bluffs of the bayou represent what would be seen in a vertical section through the chert-capped

region to the east or west. The St. Clair limestone, where it occurs on the bluffs of this part of the bayou, is in many places more or less stained with manganese and occasionally contains the larger masses of ore. But the formation is exposed in its undecomposed state, and decay has not yet caused the accumulation of any residual clay. At a point about four miles north of Batesville, and on the east side of the bayou, seventy feet of the upper part of the bed are exposed. Here it is of a dark gray or brownish-gray color, contains many fossils and weathers in slaty slabs, breaking off at a high angle to the bedding. An analysis of this rock shows the presence of 1.15 per cent of manganese finely disseminated through it, while elsewhere in the neighborhood nodules of ore have been found in the same rock. A drawing of the bluffs at this locality is given in chapter VIII.

The first outcrop of the Izard limestone appears half a mile below the confluence of Cave Creek with Polk Bayou. It crops out at the base of a cliff of the St. Clair limestone and is sharply distinguished from the latter, not only by its bluish-gray color, but by the smooth weathering of its surface, which is in marked contrast with the crumbling, granular appearance of the weathered surface of the overlying formation. To the north, up the valley of Polk Bayou and its tributaries, the outcrops of the Izard limestone become much more numerous and often comprise large areas of country.

The Maxfield tract.—The Maxfield tract is in 14 N., 6 W., section 30, the northwest quarter of the northeast quarter. A few hundred yards above the mouth of Cave Creek, a hollow makes down from the northwest and a small creek runs out of it into Polk Bayou. The Izard limestone is exposed at the mouth of the creek and the St. Clair limestone occurs for over half a mile up it. The ravine heads in the side of a high chert-capped hill rising four hundred feet above Polk Bayou. At the foot of the hill several small pits have been sunk for manganese. The ground is covered with loose chert to a depth of from two to six feet, and below this is the ore-bearing clay. The ore is of a black, massive, or crystalline variety often containing small cavities filled with clay. The clay enclosing

the ore is of a reddish-brown color and contains fragments of chert and St. Clair limestone ("gray rock"). The decayed surface of the limestone underlies the ore and clay. It is of a dark chocolate-brown color and contains many seams and specks of manganese. The "ore dirt," in the principal opening, is four to eight feet in thickness.

The following twenty-six analyses represent the composition of car-load shipments of manganese ore from this property. Analyses 3, 4, and 5 were made by the North Chicago Rolling Mill Company, and the remainder by the Illinois Steel Company, Chicago.

Analyses of manganese ore from the Maxfield tract.

No.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.
1	44.69	9.18	3.23	0.319	.....
2	41.08	10.75	.....	0.467	.....
3	43.12	12.50	1.54	0.339	.....
4	42.74	4.95	10.41	0.385	.....
5	31.90	11.20	20.50	0.347	.....
6	24.31	21.63	14.82	0.252	.....
7	24.50	28.72	5.22	0.226	.....
8	27.49	23.40	7.08	0.405	.....
9	29.57	23.40	5.10	0.452	19.00
10	31.56	21.47	6.75	0.385	16.40
11	26.82	24.42	7.33	0.273	16.20
12	27.55	24.00	7.46	0.268	15.50
13	30.55	21.70	6.48	0.328	15.00
14	33.21	18.80	6.05	0.194	15.10
15	30.55	21.70	6.48	0.328	15.00
16	31.35	20.70	4.49	0.581	14.50
17	37.59	12.70	5.56	0.357	18.20
18	34.38	17.70	4.03	0.476	21.50
19	36.05	15.50	4.87	0.279	18.30
20	37.27	15.30	4.55	0.481	21.10
21	28.69	23.00	5.42	0.788	20.00
22	33.80	16.85	5.70	0.596	19.10
23	34.03	11.20	3.65	0.732	16.30
24	36.18	14.70	3.97	0.608	18.50
25	35.40	15.70	4.35	0.735	16.30
26	36.86	15.20	3.68	0.585	12.00

This property is a good example of the derivation of the ore and its associated clay from the St. Clair limestone. The gradual decomposition of this rock at the head of the ravine has set free the ore that it contained, as well as the brown clay that was disseminated through it. These have collected in hollows on its decaying surface, and fragments of chert from above have rolled down and covered them. Though the "ore dirt" is shallow on account of the limited amount of decomposition which the limestone has undergone, yet the large amount of ore in the rock has given rise to a considerable quantity in the clay. Several car-loads of manganese ore were mined here in 1889 under the direction of Messrs. Skinner and Abbot, but it was found that it contained too much phosphorus and work was abandoned. (See analyses, page 224).

The Simmons tract.—The Simmons tract is in 14 N., 6 W., section 29, the northeast quarter of the northwest quarter. This is just north of the mouth of the last mentioned ravine and in the bluff on the west side of Polk Bayou. It is the property of Mr. S. Simmons, of Batesville. The manganese occurs in an elongated pocket in the St. Clair limestone, striking N. 18° W. across the almost horizontal bedding of the rock. The pocket dips almost vertically, with a slight inclination to the east, and is two to three feet in width. The ore is in the form of seams and pockets varying from one inch to two feet in thickness, and is associated with an indurated, brownish-red clay containing many rounded fragments of a massive red or gray calcareous rock, one quarter to one inch in diameter. The latter look like fragments of the limestone strata that often occur at the base of the chert. The ore varies much in character, from crystalline to a massive, botryoidal, or stalactitic variety. The sides of the deposit are very irregular, with "feeders" running off in various directions, but the contact with the country rock is sharp and well defined. The latter is a coarsely crystalline limestone of a pink or purplish-brown color, and contains many small masses and interbedded lenses of manganese ore. These become more and more numerous as the sides of the main ore deposit are approached.

The deposit runs diagonally up the slope of the bluff and has been opened at various places for seventy-five yards along its course. It seems probable that it occupies a cavity made by water along a crack or joint and filled up with residual clay and ore from the part of the limestone that had been dissolved, as well as by limestone pebbles from above.

Local features.—Ascending the west side of Polk Bayou from the mouth of Sullivan Creek, the St. Clair limestone is much more decomposed than to the south, and its outcrops are almost entirely covered by loose chert. It sometimes crops out at the heads or on the sides of ravines, and these exposures show it to have suffered greatly from the action of weathering. The ore-bearing clay that has resulted from this decay, exists below the chert that covers the tops and slopes of the hills, as has been proved by prospect pits. The chert still preserves a considerable thickness, but has become much shattered by the removal of the underlying limestone, and has already become thinner than to the south. The Izard limestone still preserves its original, or almost its original thickness. The first outcrop of the underlying saccharoidal sandstone, seen going north along the Bayou, appears about three miles above the mouth of Sullivan Creek. From here on it forms the predominating rock of the creek bluffs, sometimes rising up in perpendicular ledges, fifty to ninety feet in height and capped by the overlying rocks.

The Criswell tract.—The Criswell tract is in 14 N., 7 W., section 24, the northeast quarter of the northeast quarter. This property is on the west side of Polk Bayou and about one and a half miles above the mouth of Sullivan Creek. The ore is associated with the characteristic purplish-red clay and overlies the surface of the Izard limestone. The St. Clair limestone is not seen here, but is exposed half a mile to the west in the head of a ravine, and it is probable that it underlies some of the chert-covered area in the western part of this property. No mining has been done, but about a ton of ore has been collected on the surface and piled up.

The Castile tract.—The Castile tract is in 14 N., 6 W., section

18, the southwest quarter of the southwest quarter and the northwest quarter of the southwest quarter. The ore on this property occurs in the same manner as at the last place. It is associated with a red clay and lies on the decayed surface of a hill of Izard limestone. The top of the hill is capped with loose fragments of chert associated with ore and clay. The chert bed has been almost entirely removed. The St. Clair limestone has completely decayed and the only remains of it are the ore and the clay. Several small pits have been dug which show the presence of a hard, steel-gray crystalline ore, often containing small cavities filled with red clay.

The following analyses represent the composition of two car-loads of manganese ore from this property. It was mined by Messrs. Skinner and Abbot, and was analyzed and bought by the Illinois Steel Company, Chicago.

Analyses of manganese ore from the Castile tract.

Manganese	55.45	57.13
Iron	2.95	1.89
Silica	5.60	5.39
Phosphorus	0.117	0.078
Moisture	1.30	1.30

The ore as represented by these analyses is of first class quality, being high in manganese and low in silica and phosphorous.

The Button mine.—The Button mine is in 14 N., 7 W., section 24, the northwest quarter of the southeast quarter. Several small pits have been made on this property. The accompanying figure 13 is a section through one of them, and shows a part of the decaying St. Clair limestone enveloped in the clay. The ore-bearing clay, where seen, is eight to ten feet in thickness and, probably, in many places is considerably thicker. It contains many angular chert fragments. Overlying the clay is a bed varying from a few inches to several feet in thickness of a brown, sandy, drift material containing not only the angular chert, but also rounded pebbles, as well as a few partly decomposed masses of manganese ore which have been derived from the underlying

deposit. This represents the altered surface of the ore deposit as explained on page 198. Three hundred tons of ore are said to have been shipped from this property.

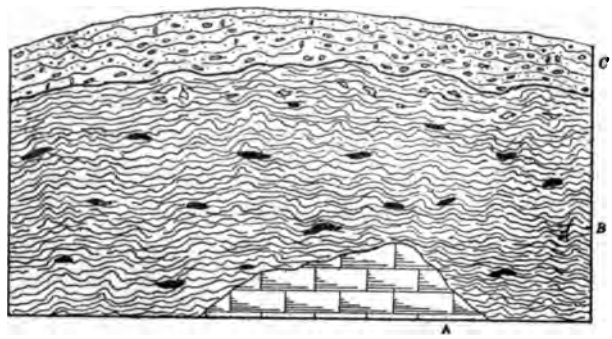


Figure 13. *Section at the Button mine showing the manganese-bearing clay and the decayed St. Clair limestone.*

A. St. Clair limestone.
B. Manganese-bearing clay.
C. Surface pebble deposit.
The black markings are manganese ore.
Horizontal and vertical scale: 1 inch—6 feet.

POLK BAYOU BASIN—*Cave Creek region.*

General features.—Cave Creek rises in the northeast part of township 14 north, 6 west, and flows southwest, emptying into Polk Bayou in the central part of the same township. The creek heads in the chert hills to the southwest of Hickory Valley, but a short distance below its source it has cut down, as shown on the map, to the underlying St. Clair limestone. In less than two miles below its source it has reached the still lower Izard limestone, which forms a larger part of the bed of the stream thence to its mouth. Many small tributaries of Cave Creek have cut through the successive formations in a similar manner and, though they are rarely over a mile in length, they have a similar structure to that of the lower Cave Creek valley; except that most of them, not having cut deep enough to reach the Izard limestone, flow in valleys of the overlying St. Clair limestone. This erosion has exposed the St. Clair limestone to the action of surface decomposition, and in many places, especially in the upper

part of the Cave Creek valley, considerable quantities of manganese-bearing clay have collected on its decayed surface. In the lower part of the valley, however, a larger part of the limestone still remains, especially back in the interior of the hills where it has been protected by the overlying chert. Consequently the ore-bearing clay is not in such large beds, as, other things being equal, it would have been, had more of the limestone been decomposed. But the fact that the limestone is often rich in manganese largely counterbalances the limited decomposition that has gone on, and the small deposits of residual clay have, in many places, been found to contain considerable quantities of manganese ore. The thick, protecting cap of chert which exists on the tops of the hills has also saved the clay and ore from being washed away, and has thus preserved practically all that was originally set free from the limestone.

One of the most noticeable features of the Cave Creek valley is the frequent occurrence of caves; hence the name of the creek. The caves usually occur in the St. Clair limestone, but sometimes in the Izard limestone. The road up the creek skirts the hills on the southeast side of the valley for some three miles from its mouth. The hills rise a hundred feet or more above the creek, and in their lower slopes the St. Clair limestone often forms a steep ledge, in the face of which are the openings to many caverns, running back into the hills in numerous intricate passages and small chambers. No large chambers have been found, but the hills are often cut up in a labyrinth of narrow channels. Stalactites are often seen, but are not in large quantities. Many of the caverns are the haunts of bats which have, in some places, given rise to deposits of guano. The underground passages seem to have a general direction at right angles to Cave Creek and may possibly represent the remains of an ancient underground drainage into Polk Bayou or the White River.

The Chinn tract.—The Chinn tract is in 14 N., 6 W., section 28, the northwest quarter. Ascending Cave Creek from Polk Bayou, the first place where prospecting has been done is on this property, in a small ravine which makes down from the hills and

opens into Cave Creek bottom. The tops of the hills are capped by chert, and the slopes of the ravine are covered by loose fragments that have rolled from above. Several small prospect pits have been dug on the sides of the ravine and have shown the presence of manganese ore of a hard, iron-gray variety, containing small cavities filled with earthy matter. The extent of the clay enclosing the masses of ore has not yet been determined as the prospect pits have not gone through it. It is undoubtedly underlain by the decomposed surface of the St. Clair limestone, as that rock is exposed at the same level in the bluffs of Cave Creek, a few hundred yards to the north.

The Clinton Trent tract.—The Clinton Trent tract is in 14 N., 6 W., section 22, the northwest quarter. Several prospect pits have been dug on this property at the base of the chert bed that caps the hills on the northwest side of Cave Creek. The pits show the presence of considerable quantities of manganese ore imbedded in dark chocolate colored clay. Some of the ore is finely crystalline and in the form of lumps and nodules. In one pit, numerous small nodular masses of ore, as large as variously sized shot ("shot ore") occur. This variety, if it can be found in sufficient quantities, can be profitably saved by washing it free from clay. The thickness of the deposit has not yet been determined and the underlying rock is not exposed in the prospect pits, but, judging from the character of the surrounding hills, the deposit doubtless lies in the hollows of the St. Clair limestone ("gray rock"). The chert, in one place, dips at 75° N. 20° W., an occurrence which is brought about by the leaching away of the underlying limestone and the subsidence of the chert bed, as explained on pages 191–196.

Southeast of this place, on the east side of the creek, and still on the land of Mr. Trent, another prospect pit has been made at the base of the chert and above the outcrop of St. Clair limestone. In the bottom of it, a mass of crystalline ore three feet in diameter, containing small cavities filled with dry, black clay, has been exposed.

The O'Flinn mine.—The O'Flinn mine is in 14 N., 6 W., sec-

tion 22, the southwest quarter of the northeast quarter. The ore on this property occurs in somewhat the same associations as at the Cason place, in a hard indurated clay of a more or less sandy consistency and of a massive or slaty structure. The deposit is interstratified with the St. Clair limestone and represents the manganese in place in that formation. The accompanying figure 14 represents a section of the hill in which the deposit is exposed and shows its mode of occurrence.

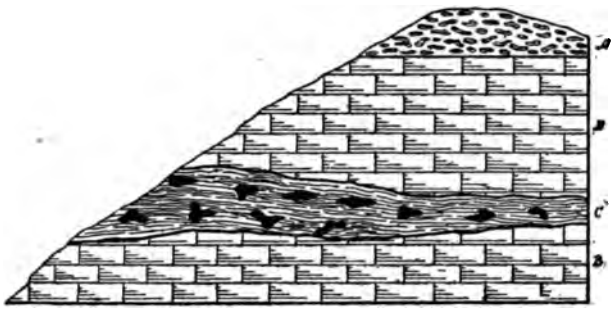


Figure 14. *Section showing the occurrence of manganese ore at the O'Flinn mine.*
A. Boone chert.
B. St. Clair limestone.
C. Manganese-bearing deposit.
The black markings indicate manganese ore, but are exaggerated in size.
Horizontal scale: 1 inch=500 feet. Vertical scale: 1 inch=100 feet.

The manganese is sometimes in large masses of hard, steel-gray ore, one to three feet in diameter, and sometimes in smaller masses or in flat concretions ("button ore") imbedded in the earthy deposit. The enclosing material is usually of a red or brown color, but is frequently streaked with black bands, due to a stain of manganese.

A shaft was once sunk in the St. Clair limestone here in search of gold and silver, but has been abandoned. It is now mostly filled with water, but is said to be 103 feet deep. Many masses of a pink St. Clair limestone, containing inclusions of red and green clay and cavities lined with crystalline quartz and white calcite are on the dump. Veins of calcite also traverse the limestone bed, but the rock from which the gold and silver is said to have been taken is a hard, massive, dun-colored quartz, of a somewhat granular structure,

frequently containing small cavities lined with red, transparent quartz crystals. This rock is said to have lain almost horizontally and to have been eighteen inches in its thickest part. It probably represents a lenticular bed in the St. Clair limestone.

The Geo. D. Reves tract.—The George D. Reves tract is in 14 N., 6 W., section 15, the southeast quarter of the southwest quarter, and is situated less than a mile above the O'Flinn place, in the Cave Creek valley. The St. Clair limestone crops out in many places along the sides of the hill, and its exposures are separated by areas of residual clay with masses of manganese ore and fragments of chert. Several small pits dug along the line of contact of the chert and St. Clair limestone for a distance of several hundred yards, all show the presence of more or less hard, steel-blue, massive ore.

The E. H. Woodward tract.—This property is in 14 N., 6 W., section 16, and is controlled by E. H. Woodward and Company. It shows indications of manganese in its eastern and northwestern parts, but very little work has been done on it. Fifteen tons of ore are said to have been mined and shipped.

The Trent mine.—The Trent mine is in 14 N., 6 W., section 10, the southwest, northwest, and northeast quarters of the southeast quarter, and is the property of the Ferro-Manganese Company (E. H. Woodward and Company). It will be seen on the map that a small creek heads in the chert hills in the southern part of sections 10 and 11 and runs south through this property into Cave Creek. It has cut its channel through the chert bed and almost through the St. Clair limestone ("gray rock"). The bed of the stream is still in the latter rock, and the underlying Izard limestone is not seen until the confluence with Cave Creek is reached. On the slopes of the hills along this tributary, the manganese-bearing clay is exposed in many places.

The Trent mine was worked by E. H. Woodward and Company between 1881 and 1887 and two large pits were

sunk to a depth of twenty feet, while a shaft was sunk considerably deeper. In some places the unevenly decomposed surface of the St. Clair limestone has been found, underlying the ore-bearing clay. The property is not being worked at present.

The ore occurs in both small and large masses, from a fraction of an inch to several inches in diameter. These are scattered irregularly through a clay bed which varies from ten to probably thirty or forty feet in thickness, and in some places runs to still greater depths in hollows in the limestone. There are considerable quantities of small ore ("wash dirt") which could be easily saved with proper washing facilities.

The accompanying figure 15, though on a small scale, shows the relation of the ore-bearing clay to the chert and

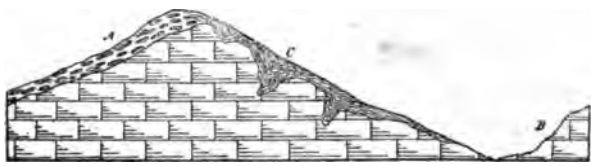


Figure 15. *Section through the hill at the Trent mine showing the formation of manganese-bearing clay on the decayed surface of the St. Clair limestone.*

A. Boone chert.
B. St. Clair limestone.
C. Manganese-bearing clay.
Horizontal scale: 1 inch=500 feet. Vertical scale: 1 inch=200 feet.

St. Clair limestone. It will be observed that the clay occurs on the slopes of the hills and below the base of the chert bed, and that it lies in hollows in the decayed surface of the St. Clair limestone, from which it has been derived. It is frequently covered with loose fragments of chert that have rolled from above.

The St. Clair limestone is sometimes of the purplish-red variety, but is generally of a light gray color. It frequently contains seams and nodules of manganese ore from a third of an inch to three inches in diameter. A part of the decayed surface of the St. Clair limestone, as exposed in one of the large pits, is shown in figure 9, page 169, and is described there. It contains nodules and seams of ore which lie in the planes of bedding of

the rock and often show a more or less laminated structure. Thin films of red clay separate the laminae and frequently coat the nodules of harder ore. A thickness of ten to fifteen feet of ore-bearing clay overlies this exposure and runs down to unexplored depths in hollows in the limestone.

It is only the ore in the clay that can be profitably mined, however, and this is of the hard, crystalline or massive variety similar to some of that in the rock.

Three hundred yards southeast of the above mentioned pit, is another opening, showing similar ore, clay, and limestone, except that the limestone does not contain the seams and nodules of manganese seen in the other pit. Joints with deeply striated faces (slickensides) are numerous in the clay, and are due to the gradual sinking of that bed as it was slowly formed by the decomposition of the limestone. Striated films of clay sometimes adhere to the granular surface of the peaks of limestone that protrude into the ore-bearing bed, and these, doubtless, are the records of the sinking of the clay around a resisting point.

Many other small openings have been made in the hollow in which the Trent mine is situated. They all show similar ore in similar associations and do not require further mention. They serve to prove the very general presence of manganese in this locality.

The Privet tract.—The Privet tract is in 14 N., 6 W., section 11, in the upper part of the Cave Creek valley, a little over a mile east by north from the Trent mine. It is the property of Mr. Simon Adler, of Batesville. Several small prospect pits were dug in 1886 and thirty tons of ore are said to have been shipped. The pits are now mostly filled up.

The ore deposit occupies the lower slopes of the west side of a hill which is capped by a knob of chert forty feet or more in thickness. Fragments of ore have frequently been washed out of the enclosing clay and have collected in small gullies on the hillside. Masses of gray St. Clair limestone occur in the clay, but the main body of that formation is not seen in place. There is doubtless a considerable thickness of clay here, but the quantity of ore in it remains to be determined.

Other localities on Cave Creek.—Between the various places already described on Cave Creek, there are numerous other localities where manganese has been found, and doubtless there are many more, covered by loose chert from the hills, that have not yet been discovered. Those mentioned, however, comprise most of the places where work has been done. The other localities that have been found show ore on the surface, mixed with the red clay and loose chert, but have not yet been tested as to extent.

To the north and northeast of the Privet property there is a high, rugged, chert area comprising the region of the headwaters of Cave, Miller, North Dota, and Coon Creeks, the last a branch of Sullivan Creek fork of Polk Bayou. To the west of this chert region is the manganese area of Coon Creek and other tributaries of Sullivan Creek, which will be described later in this chapter. To the east no manganese has been found, though the St. Clair limestone is exposed in the bluffs of the upper part of Miller Creek for over two miles. The limestone in this locality is of a gray or light pink color and contains no visible manganese ore, though an analysis of a sample of it from St. Clair Spring, on the east side of the Batesville and Hickory Valley road, shows the presence of less than 0.2 per cent finely disseminated through it, probably in the form of carbonate of manganese. Still farther to the east, beyond the Miller Creek exposures, no manganese has been found, and the barren chert hills of the upper part of Dota Creek form a natural boundary to the manganese region.

POLK BAYOU BASIN.—*East side of Sullivan Creek.*

General features.—The summit of the divide between Cave Creek and Sullivan Creek is an exclusively chert area with the characteristic rough, barren topography of a region underlain by that rock. On both sides of the divide the numerous tributaries of the two streams have cut through the chert into the underlying St. Clair limestone, and beds of ore-bearing clay, derived from the decay of the latter, have resulted from this exposure. The deposits on the tributaries of Cave Creek have already been

described. Those on the west or the Sullivan Creek side, resemble the latter in most respects, except that in the northern part of the Sullivan Creek drainage, more of the St. Clair limestone has been decomposed and the capping of chert is much thinner than in many parts of the Cave Creek basin. Most of the manganese openings on the west side of the divide are in the basin of Coon Creek. South of that area, between Coon Creek and the mouth of Sullivan Creek, manganese has been found, but very little development work has been done.

The Sullivan Creek basin differs markedly from the Cave Creek basin in that it has not only cut through the chert, the St. Clair limestone, and into the Izard limestone, as in the case of the latter stream, but it has reached the still lower saccharoidal sandstone, and this rock forms the bed of the creek throughout the manganese region. Its tributaries, however, as far north as Coon Creek, run mostly in basins of the overlying rocks.

The Perrin tract.—The Perrin tract is in 14 N., 6 W., section 8, the southeast quarter. Manganese has been found in several places on it in association with a red or brown clay. The ore occurs either as crystalline nodules of a dull, black color on the outside and a bright steel-gray inside, or as a more massive material in larger bodies, often containing small cavities. The ore outcrops on the slopes of the hills at the base of a heavy chert capping. The St. Clair limestone is not seen, and on parts of the property it has probably entirely decayed, while in other parts it doubtless exists as knobs under some of the chert-covered hills. As a result of this extensive destruction of the limestone, considerable deposits of clay with a variable amount of ore are to be expected. The depth of the deposits has not yet been tested, but several small pits on the slopes of the hills prove the presence of manganese ore and its accompanying clay. Forty tons of ore are said to have been taken out of one of the prospect pits.

A similar ore occurs with the same associations in 14 N., 6 W., section 8, the southeast quarter of the northeast quarter, on the land of John Wilson, and also in the adjoining section 9, on the east half of the southwest quarter. Very little work has

been done in this area, however, and the ore is only seen in loose masses on the slopes of the hills.

The Hunt tract.—The Hunt tract is in 14 N., 6 W., section 10, the southwest quarter of the northeast quarter. It is also known as the Kelly tract or Ramsey tract and is in the hills south of Coon Creek, about two miles east of the Perrin tract. Here, as in the properties just mentioned, the hills are heavily capped with chert, and loose fragments have rolled from above and have completely covered the slopes. Several small prospect pits, dug through this loose material, have shown the presence of a hard, massive, iron-gray ore buried in a red clay. The St. Clair limestone is not seen, but the character of the hills and the way the chert lies on the steep slopes suggests the probability that it underlies a large part of the higher land. This property adjoins the Trent mine on the north, and, though not enough work has been done on it to actually prove the extent of the manganese-bearing clay, yet the same indications that prevail at that mine are seen here.

The Edward Hunt tract.—The Edward Hunt tract is in 14 N., 6 W., section 11, the southeast quarter of the northwest quarter and the southwest quarter of the northeast quarter. It is heavily covered with chert, but the St. Clair limestone is exposed in some of the ravines. Several small pits have shown the presence of manganese ore on the slopes of the hills at or below the base of the chert bed and overlying the decayed surface of the limestone. The ore is associated with clay of a dark purplish-chocolate color, and is a coarsely crystalline, steel-gray variety. The St. Clair limestone is of the same color as the clay, and contains masses and seams from one inch to eight inches in thickness, of the same kind of ore as is found in that bed.

This property is an excellent example of the origin of the manganese deposits from the decomposition of the limestone, and as a result of such a mode of origin, it may be expected in a case like this, where the limestone contains considerable quantities of manganese, that deposits of ore-bearing clay can be found, which will depend for their extent on the amount of the decay of the rock. It also follows that the places to look for such ores

are along the sides of the hills, in the hollows in the limestone ledges, since these hollows are formed by the decomposition of the limestone, and this means the formation of ore-bearing clay.

The J. B. Gray tract.—The J. B. Gray tract is in 14 N., 6 W., and covers all of the west half of section 2, except the northeast quarter of the northwest quarter and the northeast quarter of the southwest quarter. This property is situated near the headwaters of Coon Creek, and consists largely of an Izard limestone area covered, to a greater or less extent, with red clay carrying a variable amount of ore and loose fragments of chert. The thick covering of chert seen to the south has been mostly eroded, though it frequently occurs as small isolated knobs capping the clay covered hills. The St. Clair limestone is not seen and probably has mostly, and in many places altogether, decayed. The result of the decomposition of the limestone has given rise to the ore-bearing clay that overlies the property, and the removal of the chert has exposed this clay in many places, and has given the country a less rugged appearance than the chert areas to the south. In some parts of the property the ore deposit has suffered from this exposure and has been partly carried away by surface waters; but in many places, especially where some of the chert remains, it has a considerable depth.

Several small pits have been dug on the property and sixty-three tons of ore have been shipped by the owner, Mr. J. B. Gray. The analyses of three car-loads given below show a high grade ore. It was analyzed and bought by Carnegie Bros. and Co., of Pittsburg.

Analyses of manganese ore from the J. B. Gray tract.

Manganese	50.81	46.36	49.36
Iron	2.90	8.53	5.97
Silica	2.50	4 25	3.90
Phosphorus	0.126	0.128	0.156
Moisture	.....	2.50	5.50

The McGee tract.—Manganese ore occurs in varying quantities on the McGee Tract, on Coon Creek, to the south and southwest of the Gray tract, as well as elsewhere in the same

region. One car-load of ore is said to have been shipped from the McGee tract by E. H. Woodward and Company.

The Milligan tract.—The Milligan tract is in 14 N., 5 W., section 6, the northeast quarter of the northwest quarter, on the northern escarpment of the hills that lie at the headwaters of Cave, Coon, and North Dota Creeks. A few scattered fragments of manganese ore lie on the slopes, associated with loose chert and masses of St. Clair limestone. Frequently loose masses of a bright, glossy iron ore (limonite), of a brown or black color, occur with the manganese. The property represents the northeastern limit of the manganese ores in this part of the region. Occasionally a little ore is found for a short distance beyond, but it is in small quantities and rapidly disappears altogether.

In the face of the hills in which the Milligan property is situated, the St. Clair limestone sometimes crops out with the chert bed above and the Izard limestone below. To the north of this region, however, the St. Clair limestone, if it ever existed, has been entirely removed, as well as any residual clay and manganese ore that may have been formed from its decomposition. The country is largely an area of Calciferous sandstone, studded with outliers of Izard limestone, the latter occasionally capped with chert. It may be said, therefore, that in the country east of Sullivan Creek the line between townships 14 and 15 north marks the northern limit of the manganese region.

POLK BAYOU BASIN.—*The Polk Bayou and Sullivan Creek divide.*

General features.—Between Polk Bayou and the lower part of Sullivan Creek, there is a hilly country composed largely of Izard limestone. The outcrop of this rock extends in a long narrow tongue from the confluence of the two streams northward for five miles, until it finally thins out in the sandstone country still further to the north. On both sides of this limestone divide, the streams have cut down to the underlying sandstone, and belts of that rock follow along their courses as shown on the map. The St. Clair limestone, which once overlay the Izard limestone, has entirely decayed, with the exception of a few small knobs or loose masses in the residual clay. The chert bed

still exists in spots, though it has a greatly diminished thickness and forms a far less prominent feature of the country than on the divide between Sullivan and Cave Creeks. In many places, the residual ore-bearing clay is exposed on the surface, giving rise to rounded hills with red clay soils. As the result of this exposure, the manganese-bearing clay and its ore have often been almost entirely eroded away and remain only where hollows in the Izard limestone have saved them. But, when a protecting cap of chert exists, the ore and the clay, where they have been formed, still preserve a considerable thickness.

For a distance of about a mile north of the confluence of Sullivan Creek and Polk Bayou, the Izard limestone on the divide has been completely denuded of both chert and ore-bearing clay, and exists in low rocky ledges, becoming higher and higher to the north, until the ore-bearing region is reached.

The John B. Skinner tract.—This part of Mr. Skinner's property is in 14 N., 6 W., section 18, the northwest quarter of the northwest quarter, on the summit of the divide between Polk Bayou and Sullivan Creek, which here rises almost two hundred feet above those streams. Manganese ore occurs in association

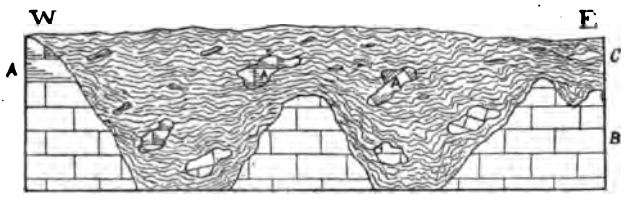


Figure 16. *Section at the John B. Skinner tract showing the manganese-bearing clay in the hollows in the decayed surface of the Izard limestone.*

A. St. Clair limestone.
B. Izard limestone.
C. Manganese-bearing clay.
Horizontal and vertical scale: 1 inch=25 feet.

with a red clay in the form of masses from one to six inches in diameter, and of small fragments and concretions ("shot ore"). Numerous fragments of chert, Izard limestone, and St. Clair limestone also occur in the clay. The deposit, as shown in the accompanying figure 16, lies in the hollows in the surface of the Izard limestone, which has been deeply scored with irregular

holes and cavities by the dissolving action of surface waters. It is to the existence of these hollows that the preservation of the "ore dirt" is due, since the covering of chert has been entirely removed and the clay and ore have been exposed to erosion, which has carried away a larger part of them and would doubtless have carried off the rest, had it not been held in the holes in the limestone.

The dependence of the preservation of the ore on the hollows in the Izard limestone is shown in figure 17, which

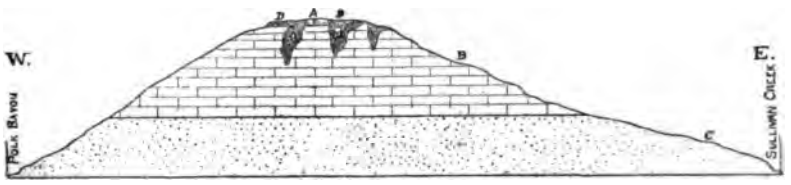


Figure 17. *East-west section across the Polk Bayou and Sullivan Creek divide in township 14 N., 6 W., sections 17 and 18.*

A. St. Clair limestone.

B. Izard limestone.

C. Saccharoidal sandstone.

D. Manganese-bearing clay.

Horizontal scale: 1 inch=⅛ mile. Vertical scale: 1 inch=225 feet.

represents a section through this property across the divide between Polk Bayou and Sullivan Creek. It will be observed that but little manganese-bearing clay exists above the space comprised in the hollows. The Izard limestone was once overlain by the St. Clair limestone and the Boone chert, but both of these formations have been almost entirely removed. All that remains of the chert are a few scattered fragments on the surface of the hill, while the St. Clair limestone is represented by loose masses and by one small exposure in situ, capping a knob of the Izard limestone, as shown in both figures 17 and 16.* The decay of the St. Clair limestone has given rise to the ore-bearing clay, which has sunk down into the hollows formed in the Izard limestone after the overlying formation had been decomposed.

The following thirteen analyses represent as many car-load shipments of ore from this property. The first four were an-

* Figure 16 represents a part of the summit of the divide shown in figure 17.

alyzed and consumed by the North Chicago Rolling Mill Company, the remainder by the Illinois Steel Company:

Analyses of manganese ore from the Skinner tract.

No.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.
1	55.68	2.00	.....	0.172	.....
2	53.66	2.50	.....	0.209	.....
3	51.86	7.80	.....	0.141	.....
4	42.77	5.50	.....	0.523	.....
5	56.10	2.61	5.44	0.075	0.60
6	57.01	2.05	5.33	0.072	0.80
7	57.41	1.62	6.00	0.100	1.00
8	55.70	1.85	6.71	0.078	0.80
9	56.75	2.19	5.49	0.068	0.20
10	57.39	1.55	5.46	0.074	0.10
11	38.49	8.80	19.96	0.115	7.00
12	56.65	1.68	5.55	0.066	0.80
13	58.31	1.33	5.78	0.064	0.90

Continuing north from the last property, the same character of ore is seen at intervals along the Polk Bayou and Sullivan Creek divide. It is generally exposed on the hilltops or covered with a thin coating of fragments of chert. Frequently knobs of Izard limestone protrude through the clay and prove the presence of that rock at short distances beneath.

The Patterson tract.—The Patterson tract is in 14 N., 6 W., section 7, the northwest quarter of the southeast quarter; and the south half of the northeast quarter. It is on the summit of the Polk Bayou and Sullivan Creek divide and half a mile northeast of the Skinner tract. The ore is scattered through a red clay soil and is of the hard, massive, steel-gray variety, with small cavities lined or filled with black clay.

Local features.—Going north from the Patterson tract on the Polk Bayou and Sullivan Creek divide, a region is reached in which not only the whole of the St. Clair limestone, but also a part of the Izard limestone has decayed. A part of the chert bed still remains, but it is much shattered and broken on ac-

count of the removal of the underlying limestone, and now occurs in isolated areas, capping hills or long narrow ridges of the Izard limestone, while in the hollows the still lower saccharoidal sandstone appears.

Figure 2, of plate XI., represents a section in an east and west direction across the divide, along the center line of the most southerly tier of sections in township 15 N., and shows the condition of the rocks. The general dip of the rocks is a gently undulating incline to the southwest. The summit of the divide reaches about 350 feet above the level of Polk Bayou and is capped with loose chert which, as will be seen in the figure, rests on the decayed surface of the Izard limestone. Manganese is found on the slopes of the hills, cropping out at the base of the chert and on the surface of the Izard limestone. It is associated with red or brown clay and represents the residual product of a stratum of St. Clair limestone, which once occupied a position between the base of the chert and the top of the Izard limestone. The Clark and Baxter tracts, and the Baxter and Montgomery mines described below are just south of the hill represented in the center of the divide, the last two being on its immediate southern slope.

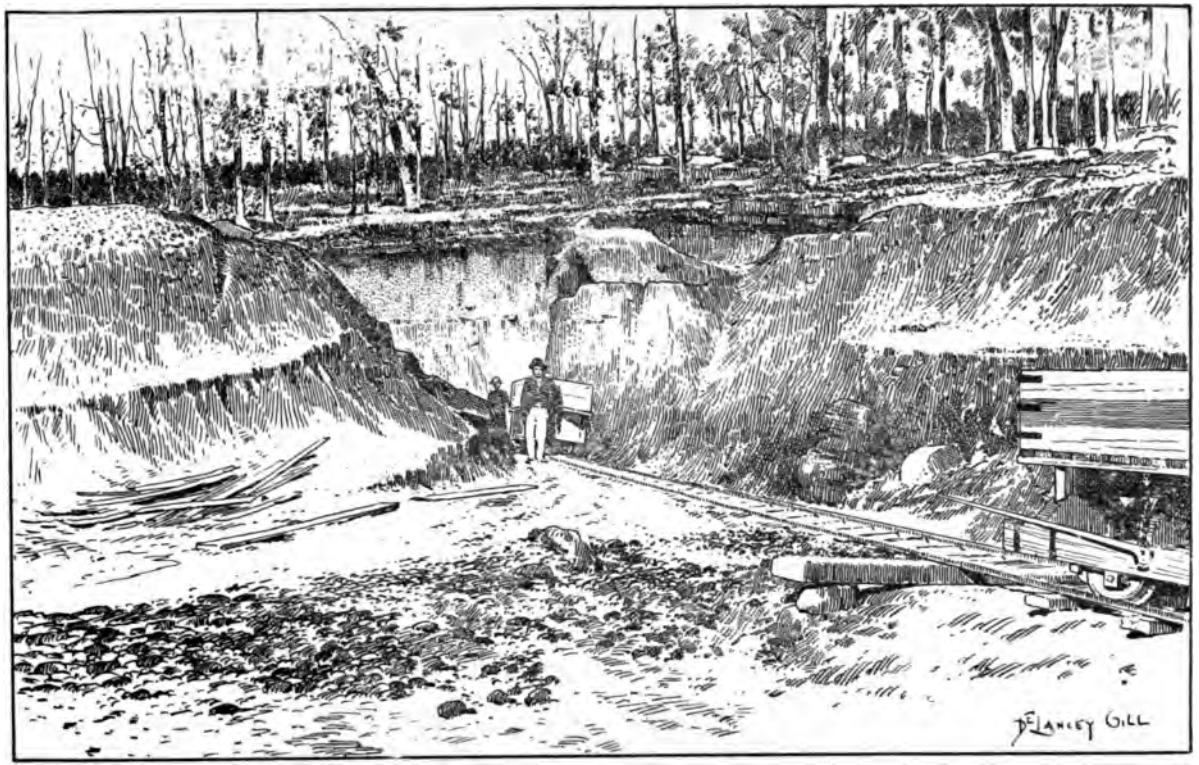
The John Clark tract—The John Clark tract is in 14 N., 6 W., section 5, the northwest quarter of the northwest quarter; and in 15 N., 6 W., section 32, the southeast quarter of the southwest quarter. This property is a mile and a half northeast of the Patterson tract and the mode of occurrence of the ore is about the same as at that place. The ore is scattered on the top and slopes of a hill west of Squire Clark's house, in loose masses mixed with red clay, angular chert fragments, and rounded pebbles. The decayed surface of the Izard limestone protrudes through the clay in many places on the slopes, but on the summit it is completely covered by the ore-bearing deposit. Several small pits have been dug, but the depth of the clay has never been determined. One pit is said to have been sunk to a depth of twenty feet without reaching the bottom of the clay. Ninety tons of ore have been mined on this property and the adjoining forty acres to the southwest.

The R. F. Clark tract.—The R. F. Clark tract is in 14 N., 6 W., section 6, the southeast quarter of the northeast quarter, and adjoins the last mentioned tract on the southwest. Both tracts form parts of the same hill, and what has already been said of the John Clark property applies also to this.

The Baxter tract.—The Baxter tract is in 15 N., 6 W., section 31, the southeast quarter of the southeast quarter; and section 32, the southwest quarter of the southwest quarter. It adjoins the John Clark tract on the west and forms part of the same hill. The ore occurs in the same manner as at that place. It is scattered in loose masses on the surface, in association with a red clay, fragments of angular chert, and rounded pebbles. What has already been said of the John Clark tract may be applied to this. The depth of the clay on top of the hill has not been tested, but the deposit will probably be found to run down into holes in the underlying limestone.

The Baxter mine.—The Baxter mine is in 15 N., 6 W., section 32, the northwest quarter of the southwest quarter and adjoins, on the north, the Baxter tract just mentioned. It is on the south slope of a hill and consists of a large pit about twenty feet deep, from which three hundred and fifty tons of ore are said to have been taken. The hill is capped with chert and the opening is made in the residual, ore-bearing clay at its base. The Izard limestone is exposed at the foot of the hill. The clay is of a red or dark chocolate-brown color, and contains masses of ore from a quarter of an inch to twenty-four inches or more in diameter. The ore is sometimes of a hard, crystalline variety, sometimes in the form of small concretions and fragments, ("shot ore") and occasionally in a porous, earthy, brown mass.

The property is now being worked by John B. Skinner and Company. The ore is carried on a tramway to Sullivan Creek, a distance of about a mile, where it is crushed and washed in a series of jigs. (See Methods of Mining in the Batesville Region, chapter XI). The accompanying drawing from a photograph represents the Baxter mine. The sides of the pit are composed of the ore-bearing clay, with loose masses of St. Clair



THE BAXTER MINE, BATESVILLE REGION, ARKANSAS.

and Izard limestones, while fragments and slabs of chert lie on the hillside.

The following analyses represent the composition of three car-loads of ore mined on this property by Messrs. Skinner and Abbot. The ore was analyzed by the Illinois Steel Company.

Analyses of manganese ore from the Baxter mine.

Manganese.....	55.60	47.70	45.77
Iron.....	8.78	4.77	4.67
Silica.....	24.58	10.98	14.06
Phosphorus.....	0.149	0.284	0.342
Water.....	9.80	9.20	8.20

Ores of considerably better quality than these are reported to be mined at present on the same property by John B. Skinner and Company.

The Montgomery mine.—The Montgomery mine is in 15 N., 6 W., section 32, the northeast quarter of the southwest quarter. It adjoins the Baxter mine on the east and resembles it in most respects. It is on the same slope of the same hill and the two pits are directly alongside of each other. The clay lies on the surface of the Izard limestone and the ore occurs in various forms, either as masses of hard, steel-gray ore, as flat concretions, ("button ore"), or as small, round, concretions and fragments of the larger masses ("shot ore", "wash dirt"). The ore could be easily freed from the adhering clay by proper washing machinery.

There are considerable quantities of loose masses of St. Clair and Izard limestone on this property, and often the two rocks are represented in the same fragment, such pieces having doubtless come from the point of contact of the two beds. The fragments of St. Clair limestone are frequently stained green with carbonate of copper and often contain nodules of the same material, enclosing a kernel of oxide of copper. The green carbonate has been formed by the chemical alteration of the latter material. The copper minerals are not in sufficient quantities to be of any commercial value.

The accompanying drawing from a photograph represents the opening at the Montgomery mine. The sides of the pit are

composed of the ore-bearing clay, while the rock in the foreground, on the right-hand side, is a mass of Izard limestone rounded off by decay. Some of the St. Clair limestone still adheres to it and in places appears to have overlain it on an uneven surface. So little of the St. Clair limestone is left, however, that sufficient evidence is not at hand to draw conclusions as to the cause of the inequality.

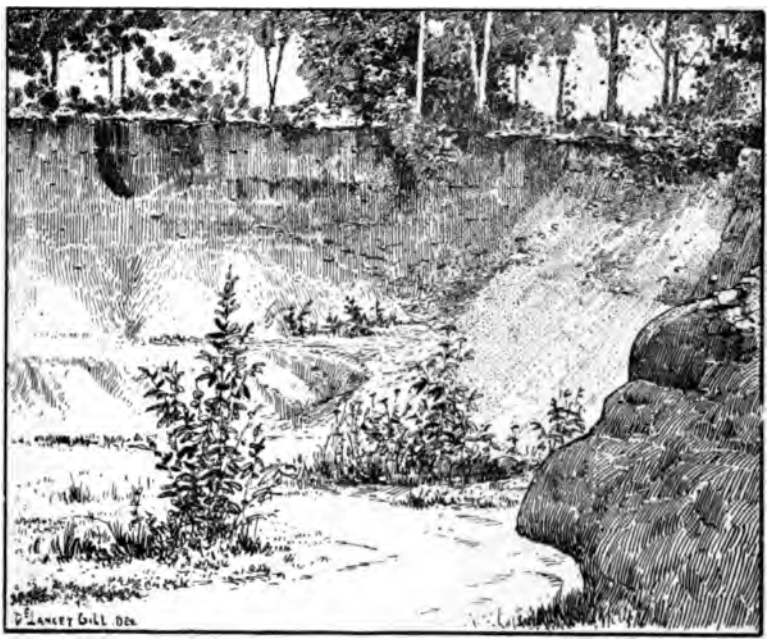
The J. P. Montgomery and J. W. McDowell tract; the J. P. Montgomery tract.—The Montgomery and McDowell tract is in 15 N., 6 W., section 31, the northeast quarter of the southeast quarter; the Montgomery tract is in section 31, the northwest quarter of the southeast quarter; the northeast quarter of the southwest quarter; and in section 32, the southeast quarter of the northwest quarter. These properties adjoin on the west and north the forty acres on which the Baxter mine is situated, and are heavily capped with chert. The Izard limestone forms the lower slopes of the hills, and in the bottoms of the hollows the underlying sandstone crops out. The St. Clair limestone is not seen and it has probably entirely decayed. What clay and ore it may have contained now lie between the chert and the Izard limestone. Numerous small pits have been sunk, some of which have struck ore.

There is frequently found here a soft, earthy, but compact ore of a jet black color, containing many joints, the faces of which are deeply striated with slickensides and have a brilliant black gloss. It represents a hardened clay* deeply stained with manganese, and is often mistaken for plumbago. It is especially plentiful in 15 N., 6 W., section 31, on the bluffs of Polk Bayou, where it frequently contains angular fragments of

*An analysis of this material made by the chemist of the Survey gave the following results:

Manganese	14.57
Iron	10.84
Silica	37.77
Alumina	9.87
Water	12.82

The harder ore found on these properties is of much better quality than the material represented in the above analysis.



THE MONTGOMERY MINE, BATESVILLE REGION, ARKANSAS.

chert, which have been blackened throughout their mass by the impregnation of manganese. In section 31, a pit is said to have been sunk into it for twenty-five feet without reaching the bottom. It frequently contains cavities lined with stalactites of harder manganese ore and is capped by a deposit of laminated, brown hematite. A dark steel-gray manganese ore has also been found in this area.

A decomposed chert in the form of a fine powder occurs on the land of Mr. Montgomery in section 31. This contains particles of the less decayed rock, and if freed from these it would make a valuable polishing powder. Masses of a light, porous, partly decayed chert are also found in association with this material and could be used for whetstones.

Besides the properties already mentioned, Messrs. McDowell and Montgomery own several other tracts of land in sections 31 and 32.

The William R. Montgomery tract.—The William R. Montgomery tract is in 15 N., 6 W., section 32, the south half of the southeast quarter, and shows manganese under conditions similar to those at other localities already described in the neighborhood.

The Morris tract.—The Morris tract is in 15 N., 6 W., section 33, the west half of the southwest quarter, and is the property of Messrs. J. W. McDowell and J. P. Montgomery. Three pits have been opened on it and several hundred tons of ore are said to have been shipped. The ore is exposed in several places.

The Bruce tract—The Bruce tract is in 15 N., 6 W., section 28, the southwest quarter of the southwest quarter; section 29 the whole of the southeast quarter with the exception of the northeast quarter of it; section 32, the northeast quarter of the northeast quarter; section 33, the northwest quarter of the northwest quarter. This tract is largely covered with rounded pebbles and angular chert, lying on low hills of the Izard limestone or the underlying sandstone. The Izard limestone becomes thin in this region and often occurs simply as small outliers on the surface of the sandstone. Frequently, however, it appears to be absent when it is only hidden under the gravelly material and

loose chert. The St. Clair limestone is entirely wanting and not even fragments of it remain. The chert bed has almost disappeared, and occasional small areas of loose, angular fragments are all that remain of it. The ore is found as masses mixed with the chert and rounded pebbles, or as a cement of a breccia, binding together fragments of the loose material, both angular and rounded. The cracks in the chert are much stained with manganese and often the whole substance of the rock is impregnated with it, turning it a black color. No mining has been done on this property and the depth of the ore-bearing deposit has not been determined. Similar ores are found on the Totty property to the south of the Bruce lands, and in the region thence east to Polk Bayou.

This area represents the northern limit of the manganese ores in the region between Polk Bayou and Sullivan Creek, and the ore deposits have already become small and scattered. To the north, the country is mostly underlain by the sandstones and magnesian limestones that form the northern boundary of the manganese area. Occasionally outliers of Izard limestone cap small hills, but they rapidly grow fewer and soon disappear altogether to the north.

POLK BAYOU BASIN.—*Prairie Creek region.*

General features.—The waters of Prairie Creek rise in the chert hills to the east and northeast of the town of Cushman and flow thence southeast, emptying into Polk Bayou less than two miles above the mouth of Sullivan Creek. The region to the south of this creek is a heavily chert-capped area and represents the belt of chert barrens that borders the manganese region on the south. It is the northwesterly continuation of the same belt that has been described as crossing Polk Bayou north of Batesville. In the latter region, the bayou has cut down through the chert and exposed the underlying limestone. In the same way the limestones crop out on the northern escarpment of the highland abutting on Prairie Creek, and numerous gullies, emptying into that creek, have made inroads on the chert and have exposed the same beds for short distances back from the main valley. It is

in the neighborhood of these exposures that manganese is found. To the north of Prairie Creek, the country is much broken and is largely composed of Izard limestone and the underlying sandstone, with numerous ridges and isolated knobs of chert.

As will be seen on the map, the St. Clair limestone is sometimes exposed in small areas both to the north and south of Prairie Creek, and in many places where it does not appear, it doubtless exists under the concealing cap of chert; but the bed, as a whole, has been considerably decomposed, and on this fact depends the existence of the deposits of manganese-bearing clay.

The Shaw tract.—The Shaw tract is in 14 N., 7 W., section 11, the northwest quarter of the northeast quarter. Manganese occurs on this property in a red clay with angular and rounded chert fragments. The rounded fragments disappear at a depth of eight to twelve feet. The ore is of the usual steel-gray, crystalline variety. Several pits have been sunk, but are now almost entirely filled up. The surface is heavily covered with loose chert and pebbles, rendering the ore-bearing clay invisible, except where it has been sunk into.

The Brooks mine.—The Brooks mine is in 14 N., 7 W., section 10, the southeast quarter of the southeast quarter; and in section 15, the east half of the northeast quarter. It is almost all heavily capped with chert, the only exposures of other rocks being at the northwestern extremity, where the Izard limestone and a small outcrop of St. Clair limestone appear. The property consists of a rolling, hilly area and marks the northern limit of the chert barrens to the south. Three shafts, thirty-five feet, thirty-six feet, and forty-five feet deep, respectively, have been sunk on the property, and it has been found that beneath the chert, on the slopes of the hills, the ore-bearing clay occurs to a considerable depth. Several drifts have also been made in the ore deposit.

Drift No. 1 runs into the side of a hill for a hundred and fifty feet, showing a stiff, red clay with angular chert and a little manganese ore. Immediately overlying the drift are ten to fifteen feet of chert, capping the hill. Drift No. 2 runs north, under the chert, into a deposit of dark chocolate-colored clay,

containing both large masses of ore ("lump ore") and innumerable small particles ("shot ore"). The mixture of "shot ore" with its associated clay is said to contain thirty-four per cent of metallic manganese. A shaft forty-five feet deep was sunk into this deposit without reaching the bottom. Masses of gray and chocolate-brown St. Clair limestone are found in almost all the shafts and drifts, and point clearly to the origin of the ore from the decomposition of the limestone bed.

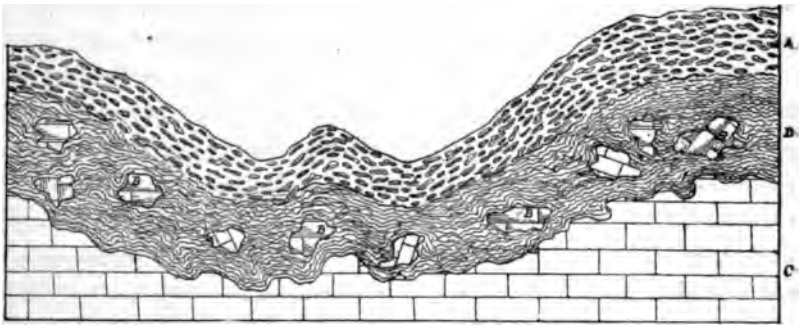


Figure 19. *Section through the Brooks property showing the formation of the manganese-bearing clay by the decay of the St. Clair limestone, and the resulting subsidence of the chert.*

A. Boone Chert.
B. St. Clair limestone.
C. Izard limestone.
D. Manganese-bearing clay.
Horizontal scale: 1 inch—300 feet. Vertical scale: 1 inch—125 feet.

The accompanying figure shows the occurrence of the ore on this property. The shafts and drifts have proved the dip and thickness of the chert at several places on the slopes of either hill, while in the intervening space the thickness and dip as represented in the figure are imaginary.

It will be seen in the figure that the ore-bearing clay rests directly on the irregularly decayed surface of the Izard limestone, and that it is capped by the chert. It will also be observed that the ore-bearing clay contains numerous loose masses of both the St. Clair and Izard limestones. Originally the St. Clair limestone extended continuously across the ravine represented in the figure and held the intermediate position, between the Izard limestone below and the chert above, that is now held by the clay with the ore and loose rock. The only difference was that it and the overlying and underlying rocks were horizontal

or almost so, and instead of there being a ravine in the center of the property, the two hills were connected on one continuous level. By the action of percolating surface waters, the St. Clair limestone has decayed, the carbonate of lime has been carried off, and the manganese ore and clay, which were once scattered through the rock, have remained in the form of the ore-bearing clay as it exists at present.

It will be seen in the figure, that loose masses of St. Clair limestone still exist in considerable quantities in the ore-bearing clay, and it is more than probable that in the hills on either side of the hollow, isolated areas of this rock, not represented in the figure, may still exist in situ above the Izard limestone. The base of the clay bed, as shown in the figure, is imaginary, as none of the shafts have reached that depth, but estimating its position from measurements of the position of the Izard limestone in the neighborhood, it is approximately correct. During the decay of the St. Clair limestone, the overlying chert has sunk down in the hollows formed by the partial removal of that rock, and hence the ravine now seen between the hills on either side of the figure. The chert exists in a loose, shattered condition, often so much broken that it forms simply a mass of angular fragments; but in some of the openings on the slopes of the hills, it can be seen dipping in towards the hollow, in a manner directly dependent on the subsidence it has undergone. (See pages 193-196.) A part of the chert in the hollow has doubtless rolled from the hillsides, but some, at least, of that on the slopes represents the remains of the original bed approximately in place, changed in position only by the amount of subsidence it has undergone. The thickness of the remaining chert varies from ten to over fifty feet.

The dark brown clay found in this mine has been successfully used in St. Louis in the manufacture of artificial brownstone and colored bricks, and several car-loads have been shipped there for those purposes.

The Whitthorne tract.—The Whitthorne tract is in 14 N., 7 W., section 10, the southwest quarter of the northwest quarter; and the northeast quarter of the southwest quarter. It is on a

chert-capped ridge that runs off from the chert region about Cushman and forms the divide between two small forks of Prairie Creek. The chert becomes thin towards the eastern end of this divide, and knobs of St. Clair limestone or areas of manganese-bearing clay frequently protrude through it. The Izard limestone is seen below in the beds of both forks of the creek. There is doubtless a considerable thickness of St. Clair limestone here, and the existence on its surface of numerous basins of manganese-bearing clay proves that, in some places at least, it is highly impregnated with the materials required to form such deposits.

Figure 20. *Section through a pit on the Whitthorne tract showing the formation of the manganese-bearing clay by the decay of the St. Clair limestone, and the resulting subsidence of the chert on the slope of the hill.*

A. Boone chert.
B. St. Clair limestone.
C. Manganese-bearing clay.
Horizontal and vertical scale : 1 inch—20 feet.

The accompanying figure is a section through a pit on the Whitthorne property. It is on the northern slope of the ridge and shows not only the leaching of the limestone and formation of the clay as a residual product, but also the sloping of the chert on the edge of the hill as the result of the removal of the underlying limestone, as explained in chapter VIII. The jagged edge of the limestone, on the right, represents the partly decayed surface of that rock. The clay is red and chocolate-brown in color, and contains the usual hard, crystalline ore in variable quantities. As will be seen in the figure, the ore-bearing clay also overlies the limestone to the right, and in this spot the chert bed has been entirely removed, and the clay is exposed in a hollow on the decayed surface of the limestone.

Similar deposits are seen elsewhere on the property, but only very little work has been done. The St. Clair limestone in some places crops out as a dark chocolate-brown rock, highly

impregnated with manganese, and elsewhere, perhaps only a few yards off, it is of a light gray color and contains but little of that material. This is a noticeable instance of the unequal distribution of manganese in the limestone, and serves to explain the frequent occurrence of masses of the pure rock in beds of highly manganiferous clay. (See pages 187-188).

The Blair tract.—The Blair tract is in 14 N., 7 W., section 9, the southeast quarter. It comprises a hundred and sixty acres at the head of one of the forks of Prairie Creek, and three-quarters of a mile southeast of Cushman. The ore occurs in association with red clay, overlying the decayed slopes of the Izard limestone. A knob of chert caps the hill and fragments of it have rolled down and mixed with the clay. Thirteen tons of ore are said to have been shipped, but very little work has been done.

Other localities on Prairie Creek.—Besides the properties already mentioned, there are many others in the Prairie Creek region which show manganese under conditions similar to those described; but little or no work has yet been done on them.

POLK BAYOU BASIN—*Northwest part.*

General features.—Continuing up the west slope of the Polk Bayou basin, north of Prairie Creek, the country becomes broken into small chert-capped hills, with Izard limestone below and the underlying sandstone in the creek beds. The chert in this region becomes thin and, in places, is only represented by loose fragments on the tops of the hills. Ore-bearing clay is frequently found on the hills and is generally mixed at its surface with the remains of the chert bed, or capped by a heavier bed of chert free from ore. Sometimes the clay has been washed down over the slopes and has collected in the hollows in the decayed surface of the limestone. The St. Clair limestone has been entirely decomposed and even fragments of it are rarely seen in the residual clay.

The Pritchett tract.—The Pritchett tract is in 15 N., 7 W., section 36, the northwest quarter of the southwest quarter; and section 35, the southeast quarter of the southeast quarter. Manganese ore, associated with red clay, has been found on this prop-

erty overlying hills of Izard limestone. Frequently bodies of chert form prominent knobs on the hills, and fragments of it overlie the surface of the ore-bearing clay on the slopes. Underneath this loose material, at a depth of from two to ten feet, ore has been found in masses from one to twelve inches or more in diameter. It is of the usual hard, black variety and is generally crystalline. Sometimes it occurs as a cement binding together fragments of chert. Several small prospect pits which have been sunk show manganese in greater or less quantities.

The I. N. Reed tract.—The I. N. Reed tract is in 15 N., 7 W., section 36, the southeast quarter of the southwest quarter, and is a quarter of a mile southeast of the Pritchett tract. The hill on which it is situated is heavily capped with chert, but to the north it slopes off gently to a hollow that separates it from the last named place. The ore-bearing clay is exposed on this slope and overlies the Izard limestone. From here the deposit runs south under the chert that caps the hill. The ore is of a massive, black variety, and is associated with red and brown clay and angular fragments of chert. Several openings have been made, and two hundred tons of ore are said to have been mined.

Other localities in the northwest part of the Polk Bayou basin.—Deposits similar to those described occur in several other places in 15 N., 7 W., section 36, the southeast and the southwest quarters, but very little work has been done on them. Going north from here, the manganese rapidly becomes less plentiful, until it disappears altogether in the northern part of the township. The St. Clair limestone does not appear at all, and the Izard limestone and the chert also become much less marked features of the country, finally occurring only as scattered outliers in the sandstone region of the upper Polk Bayou basin.

CHAPTER X.

THE BATESVILLE REGION OF ARKANSAS—*Continued.*

LAFFERTY CREEK BASIN.—*General features.*

The Lafferty Creek basin comprises the drainage area of the various forks of Lafferty Creek. The name is used here to include the western part of the Batesville manganese region, as distinguished from the eastern part, or the Polk Bayou basin.

The main Lafferty Creek is formed of two forks known as West Lafferty and East Lafferty Creeks. West Lafferty rises in the southeast part of Izard county and flows south; East Lafferty rises south of Barren Fork, in the same county, and flows southwest. They run together in the northwest part of Independence county, about a mile above the mouth of the main creek, and flow thence into the White River at a point one mile below the line between Izard and Independence counties. Three miles above the confluence of the two creeks, East Lafferty receives the waters of what is known as Middle Lafferty Creek, which rises about two miles northwest of Barren Fork. Numerous other tributaries run into each of the forks of Lafferty Creek, and among them are the Turner Creek and Blowing Cave Creek forks of East Lafferty, and many small branches of West Lafferty.

Ascending Lafferty Creek from its mouth, an almost exclusively chert area is passed through until the confluence of the east and west forks is reached. The rocks rise up in steep and often perpendicular bluffs, sometimes reaching over a hundred feet above the creek and forming a rugged canyon, swept periodically by the freshets common to this stream. The region represents the chert barrens that bound the manganese area on

the south, and is the northwesterly extension of the same belt already described as crossing the lower part of the Polk Bayou basin and lying south of Prairie Creek. From Lafferty Creek it passes northwesterly, crossing the White River above and below the mouth of that stream and bearing off into Stone county.

Near the confluence of East and West Lafferty, the St. Clair limestone rises from beneath the chert and is exposed in high ledges on both creeks. Fragments of ore sometimes occur on the hillsides, but the protecting cap of chert on the tops of the hills is thick, and the limestone has as yet been almost entirely uninfluenced by the disintegrating action of surface waters, so that there are no large accumulations of clay and ore. To the north and northeast, however, the chert is thinner, more of the limestone has been decomposed, and consequently there are larger beds of the ore-bearing clay. Farther up the valleys of both East and West Lafferty, the limestone has decayed still more and the consequent accumulations of ore-bearing clay are thicker. The chert also has been affected and has become thinner, but it preserves sufficient thickness to protect the underlying clay deposit from being washed away. Finally, as the head waters of the creek are approached, the St. Clair limestone has been entirely decomposed, and in its place there are large deposits of residual clay and the associated manganese ore. Here, however, another factor enters into the case: the ore occurs on isolated hills and ridges, and the chert bed has become thin, being often represented only by loose fragments scattered over the surface of the red clay. This has exposed the ore bed to the action of the weather, which has often carried off a large part of it. Hence one of the reasons why, in many places where the chert has been removed, there is but little ore-bearing clay, though the underlying limestone may have entirely decayed.* Sometimes, however, even where no chert is left, considerable quantities of clay have been saved in the hollows of the Izard limestone. Still farther up the basins of East and West Lafferty Creeks these isolated manganese areas grow fewer and fewer, and finally dis-

*Another reason is that in many places the original limestone did not contain the materials to form an ore-bearing bed. See pages 188–189.

THE LAFFERTY CREEK BASIN, BATESVILLE REGION, ARKANSAS.

appear altogether in the sandy region of southeastern Izard county.

The accompanying plate XIV. represents a general view looking westward over the Lafferty Creek basin from the summit of the high hill immediately north by east from Cushman. The view represents the characteristic topography of the region, and shows the undulating ridges and hills on which the manganese deposits occur. The high area in the extreme background is comprised in the Boston Mountains, to the west of the Lafferty Creek basin.

Figure 3, of plate XI., represents a profile section across the lower part of the Lafferty Creek basin, extending from Cushman in a westerly direction through the Tosh Hill and the George Hill to Penter's Bluff, and across the White River into Stone county. It will be seen that in this part of the basin, the St. Clair limestone preserves the larger part of its original thickness, and therefore the beds of ore-bearing clay, which are the results of the decomposition of the limestone, are scattered. In some places on the divide between East and West Lafferty Creeks, however, a considerable amount of decay has gone on, and the broken chert covers the beds of ore-bearing clay that lie on the partly decomposed surface of the limestone. This accounts for the irregular contact line of the St. Clair limestone and the chert, as shown in the section. The chert once overlay the limestone in a regularly stratified position, but the decay and partial removal of the latter rock, has undermined the chert and has allowed it to sink down and fill the hollows thus formed; hence the inequalities now seen at the contact of the two formations.

It will also be observed that both the St. Clair and Izard limestones, when not decayed, are thicker in the western part of the section than in the eastern part, and both may be said to reach in Penter's Bluff the maximum development that has been observed in the region. (See pages 125 and 172.)

LAFFERTY CREEK BASIN.—*East Lafferty Creek region.*

The A. G. Pitman tract.—The A. G. Pitman tract is in 14 N., 8 W., section 14, the north half of the northeast quarter,

just above the confluence of East and West Lafferty Creeks. The St. Clair limestone has suffered but little decomposition here, and only a few scattered areas of red clay and manganese ore occur on its decayed surface. The ore is often in the form of small, flat, black concretions, known as "button ore." No work has been done and the ore is only seen on the surface.

Local features.—Northeast of the last tract, up the east side of East Lafferty Creek, the St. Clair limestone is exposed almost continuously to the mouth of Blowing Cave Creek. Sometimes it is cut by deep hollows, that head in the chert area to the east and empty their waters into the main creek below. The country is heavily capped with chert and but little mining has been done. The limestone shows signs of considerable decomposition, however, and, by intelligent prospecting, manganese might be found in various places.

The Tosh Hill.—The Tosh Hill is in 14 N., 8 W., section 12. It is near the confluence of East Lafferty and Blowing Cave Creeks, and rises three hundred and sixty feet above those streams. Small areas of manganese-bearing clay occur at this locality, but the St. Clair limestone retains almost its whole thickness, and consequently the deposits are limited in extent. On the slopes of the hill, however, the rocks have undergone some decomposition, and several small prospect openings have shown the presence of ore under the loose chert that covers the hillsides.

LAFFERTY CREEK BASIN.—*Blowing Cave Creek region.*

General features.—Blowing Cave Creek rises in Blowing Cave, a mile west of Cushman, and flows west into East Lafferty Creek. A little over a mile from its source, it receives the waters of Phelps Spring Branch, which rises a mile northeast of Blowing Cave. Both creeks head in the limestone on the slopes of the rugged chert region that surrounds Cushman, while below their head waters, on the southern side of their drainage basin, the St. Clair and Izard limestones are exposed in steep bluffs, underlain by the saccharoidal sandstone and capped by a variable amount of chert. In some places the chert bed has

been entirely removed and the St. Clair limestone is exposed on the surface, while in other places, though much shattered and broken, it still retains a considerable thickness. The general character of this region is shown in the section in figure 3, of plate XI. The part of the section from Cushman to the Tosh Hill passes along the summits or upper slopes of the hills immediately south of Blowing Cave Creek.

The H. Hightower tract.—The H. Hightower tract is in 14 N., 7 W., section 18, the northeast quarter of the northwest quarter, over a mile south of east from the western slope of the Tosh Hill, and on the summit of the same chert-covered highland of which the Tosh Hill forms a part. Here the chert has been removed from a small area and the manganese-bearing clay has been exposed on the surface. The ore is of a soft, black variety and is associated with a red clay containing loose chert fragments in its upper part. Numerous large masses of St. Clair limestone are found in the clay, and, though that rock is not seen in place, it doubtless underlies the clay in considerable thickness; while the ore deposit represents the residue from the decomposition of its surface. A few small prospect pits have been dug on this tract, but the depth of the deposit has not been tested.

The Meeker tract.—The Meeker tract is in 14 N., 7 W., section 8, the west half of the southeast quarter; the east half of the southwest quarter; and the southwest quarter of the southwest quarter. It is at the head of the hollow in which Blowing Cave is situated, and in places is heavily capped with chert, while loose fragments of the same rock cover the slopes. Several small pits have been sunk through this loose material at the base of the main chert bed, and prove the presence of manganese ore. It is associated with red clay and lies in holes and basins on the slope of the St. Clair limestone. The clay bed, where seen, varies from three to eight feet in depth, but it is probably thicker in some places.

At this locality the St. Clair limestone is in its initial stage of decomposition. A larger part of the bed still remains, and therefore the deposits of ore-bearing clay will probably be found to be somewhat scattered; but the surface of the rock has already

been considerably affected, and the clay and ore may be expected, in many places, to fill hollows of considerable depth in the rock.

LAFFERTY CREEK BASIN.—*Turner Creek region.*

General features.—In the Turner Creek basin, which lies north of the Blowing Cave Creek drainage, the country has undergone a great change: the St. Clair limestone no longer exists in the high ledges seen in the latter area, but has been mostly leached away, and large deposits of manganese-bearing clay have collected under a heavy capping of chert.

Turner Creek rises in the chert-capped hills two miles northeast of Cushman and flows west into Lafferty Creek. The St. Clair limestone is occasionally exposed in small outcrops near its head waters, and much larger bodies are doubtless concealed under the chert that covers the tops and slopes of the hills; but the rock has undergone a large amount of decay, and, on the lower part of the creek it has been entirely decomposed. The region represents the northern limit, in the East Lafferty basin, of the St. Clair limestone, though formerly this rock extended farther to the north, as is shown by the presence in that direction of the ore-bearing clay.

Many of the best known properties in the Batesville manganese region are situated in the Turner Creek drainage. Among them are the Southern mine, the Turner mine, the Wren mine, the Lapham mine, the Polk Southerd tract, and numerous other properties.

The Southern mine; the ore deposit.—The Southern mine is in 14 N., 7 W., section 4, the northwest quarter of the southeast quarter, and belongs to the Keystone Manganese and Iron Company. It is three-quarters of a mile north of Cushman, on the summit of the chert-covered divide between the Polk Bayou and Lafferty Creek basins. The property consists of a hill rising over five hundred feet above the White River at Batesville, and comprises a part of the northern limit of the chert region, which, as will be seen on the map, extends continuously from two miles north of Batesville to the head waters of Turner Creek. The chert still exists to the north of this belt, but it is in isolated hills and ridges.

The Southern mine was first worked by E. H. Woodward and Company, between 1881 and 1885, during which time 2,500 to 3,000 tons of ore are said to have been mined. In October, 1885, the Keystone Manganese and Iron Company began work on it, and from that time until December 31, 1890, they produced 14,489 tons of ore, making a total output, since the first opening of the mine, of from 16,989 to 17,489 tons. This production probably represents over half the total output of the state.

The Southern Hill, on which the mine is situated, is capped on its summit by a bed of chert varying from twenty to sixty feet in thickness, and below this is the ore-bearing clay. The St. Clair limestone, which once occupied the position of the clay, has mostly decayed, and is now found in loose masses, known as "gray rock," in the clay. It is probable, however, that areas of it still exist in situ at the base of the clay and above the Izard limestone. The chert is greatly disturbed and dips at various angles from almost horizontal to almost vertical, and is much faulted, jointed, and shattered throughout. The loose fragments of it are frequently much stained with manganese on the outside, and numerous thin, black, films penetrate the cracks of the whole bed. The disturbance of the chert has not been caused by an upheaval, as is generally supposed, but by a directly opposite action, that is, by the subsidence of the bed as a result of the decay and partial removal of the St. Clair limestone that once underlay it, as explained in chapter VIII. The existence of manganese-bearing clay is directly dependent on this decay of the St. Clair limestone, and therefore the breaking up of the chert bed is a proof of the presence of the ore and clay, supposing, of course, that the original rock contained the materials for such a deposit. These facts have been fully discussed in chapter VIII., and do not need further mention here.

The ore found on this property occurs in loose masses varying greatly in size, from the small variety known as "wash dirt" to large masses weighing several tons. It is of a black color, has a bright lustre inside, and is generally of a crystal-

line structure. It often contains transparent, rhombohedral crystals of calcite, or encloses cavities coated or partly filled with red or yellow clay. The cavities probably represent spaces formerly occupied by the calcite, which has since decomposed and left the clay as a residue.

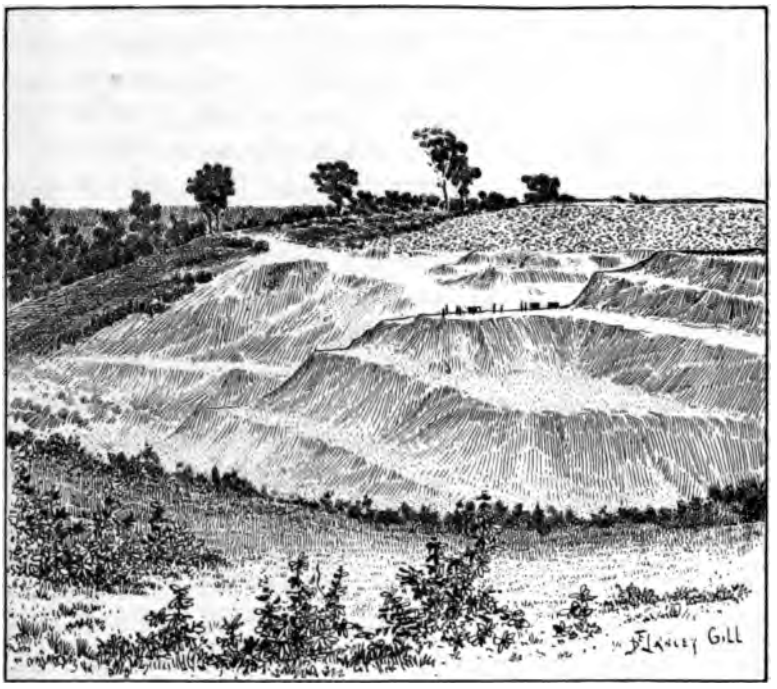
The quality of the ore, as determined by car-load shipments, varies within certain limits: the percentage of manganese ranges from 45 per cent to over 56 per cent; the iron from 1 per cent to 8 per cent; the silica from 2 per cent to 6 per cent; the phosphorus from 0.16 per cent to over 0.20 per cent; moisture from 2 per cent to 7 per cent. Large quantities of ore are at present being shipped which contain less than 0.2 per cent of phosphorus.

The following analyses represent the composition of ore from this property. The first five analyses were made under the direction of the Keystone Manganese and Iron Company and were accepted by the Illinois Steel Company, the purchasers of the ore. The sixth analysis was made by Carnegie Brothers and Company, Pennsylvania.

Analyses of manganese ore from the Southern mine.

No.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.
1	53.12	2.30	2.75	0.165	4.40
2	51.82	3.40	2.50	0.193	5.10
3	50.75	4.27	3.52	0.184	5.40
4	49.73	2.15	3.10	0.166	7.28
5	51.77	2.38	3.18	0.128	1.68
6	49.60	3.84	4.79	0.184	3.88

Judging from the surface indications on the Southern Hill, it would be expected that not only had the St. Clair limestone been largely decomposed, but also that a considerable thickness of clay existed under the chert, and contained ore in bodies of greater or less size. Such has been proved to be the case by a large number of shafts, varying in depth from twenty to eighty-five feet, which have been sunk in different places on the hill. Many of the shafts have met loose masses of St. Clair



AN OPEN CUT AT THE SOUTHERN MINE, BATESVILLE REGION, ARKANSAS.

limestone in the clay, and some have stopped on large bodies of the same rock. In the latter case the rock may either represent loose masses or else peaks of the St. Clair limestone rising up from an undecomposed area of that formation below; and it is doubtful if any of the shafts have yet reached the maximum depth of the clay. (See pages 202–203.)

The Izard limestone, which belongs in a position immediately below the St. Clair limestone, is seen at the foot of the hill; and from measurements made it is probable that in some places this rock, and in others a remnant of the St. Clair limestone, will be found to form the floor on which the clay lies at a depth of about a hundred feet from the highest part of the hill. The clay may even be found to run down into holes and basins in the limestone, and thus acquire a greater local thickness. The chert comprises the upper twenty to over sixty feet of this depth, leaving a probable thickness for the clay of from twenty to eighty feet. The latter thickness is exceptional, and points to the fact that the St. Clair limestone, from which the ore-bearing clay was derived, was heavily charged with materials to form such a deposit.

The accompanying drawing from a photograph shows a large open cut in the western side of the Southern Hill. The photograph was taken from a hill to the west of the pit and represents a view looking across a ravine. The banks occupying the central part of the drawing, where the men are standing, are composed of the clay taken out of the pit in the background and dumped on the hillside. The upper parts of the opening, occupying the extreme background of the figure, are composed of chert, and show the broken condition of that formation. Below the chert is the ore-bearing clay, from which the dump in the center of the drawing was taken.

The clay that contains the ore at the Southern mine is a stiff, red, brown, or almost black material, frequently containing many joints. The joints are due to the gradual sinking of the clay bed as it was formed from the limestone, and their faces are deeply grooved by slickensides, caused

by the movement of one part of the clay against the other. The upper part of the clay contains fragments of chert, and the main chert bed itself often protrudes into it in angular "reefs." The clay bed is of a bright red color in its upper part, but below, it contains darker layers known as "black joint." The ore, so far, has been mined only in the upper clay, and, until lately, no work had been done in the "black joint." The color of this dark bed is due to manganese, and it is not impossible that further exploration may prove the existence in it of workable bodies of ore. The difference in the colors of the clay is entirely due to the difference in character of the insoluble material in the original limestone; and there is no reason why the ore should not be found in the dark colored clay, though a practical test will be needed to demonstrate its presence or absence in workable quantities.

The manganese occurs in the clay in the form of pockets, varying greatly in the amount of ore they contain. In some places only a few tons are found, while from others five hundred tons or more have been taken. The pockets usually lie in the clay almost immediately under the chert; and this fact would suggest that the ore on this property originally occurred near the top of the St. Clair limestone.

The ore is often found, as it is expressed, "bearing off from the steeply dipping chert." This can be explained in the following manner: the base of the chert penetrates the upper part of the clay bed in a very irregular manner, now running down into it for many feet, now receding, and often piercing a pocket of ore. In the process of mining such a pocket, the ore of course ends abruptly where the chert cuts through it, but on the other side of the chert "reef", the continuation of the pocket may be found, unless indeed the chert penetrates the clay at the end of the pocket, leaving all of the ore on one side.

In sinking shafts through the chert on this property, there is frequently found, just before the ore-bearing clay is reached, a yellow or brown siliceous material of a dry,

earthy appearance and from six inches to three feet in thickness, locally known as "ochre." This is considered a good indication that the ore-bearing clay is near, for the "ochre" occurs at the base of the chert, and clay containing a greater or less quantity of ore occurs almost immediately under the chert.

Immediately below the ore at the Southern mine, the shafts frequently come on to a deposit of sand or sandy clay, ranging in thickness from four to twenty feet, and averaging probably eight feet. These deposits are called "sand bars," and vary from a loose, soft bed to a more compact and massive material. They probably represent the partly disintegrated remains of one of the sandstone beds existing in the St. Clair limestone before it was decomposed and reduced to residual clay (see pages 169 - 170). It is generally found that, in sinking through the sandy stratum, a body of St. Clair limestone is struck, and therefore the shafts usually stop when the sandy deposits are met. Between the limestone and the sand, there is very often a layer of dark brown or black clay, of the same character as the "black joint" described above, and varying from a few inches to several feet in thickness. It represents the decomposition product of the surface of the mass of limestone, and has originated in a manner similar to the rest of the clay in the ore-bearing deposit.

The mode of derivation of the ore deposit at the Southern mine and the dependence of the profitable development of the property on a knowledge of this mode of derivation, are discussed in chapter VIII., pages 199-203. The principal features may be summarized here:

The ore once occurred in the upper part of the formation known as the St. Clair limestone ("gray rock"). This formation was more than a hundred feet in thickness and was overlain by probably a greater thickness of chert. It was underlain by the bed of blue limestone (Izard limestone) which is now exposed at the base of the hill. Under the decomposing action of surface waters sinking through the bed,

the St. Clair limestone has suffered extensive decomposition. The clay has come from this decay of the limestone and represents the insoluble parts of that rock. The ore that was originally in the limestone is now imbedded in the clay. The chert that overlay the original limestone decayed less easily than the latter, and, therefore, a considerable part of it still remains. The chert has been much broken and shattered, however, because it has been undermined and gradually let down as the underlying limestone decayed. This shattering allowed the free percolation of surface waters, and consequently the more rapid decomposition of the limestone that remained, than would otherwise have been the case; yet the chert covering has retained sufficient thickness to effectually prevent the ore-bearing clay from being carried away by surface erosion.*

The Southern Hill represents an isolated area of almost complete decay of the St. Clair limestone, surrounded by areas of the same rock which have undergone much less decay, and in some places preserve almost their full thickness. To the northeast, east, and southeast of the mine, the rock is exposed in several places on the divide between the waters of the Polk Bayou and Lafferty Creek basins, especially around the head waters of Prairie Creek. To the southwest and west it crops out in almost its whole thickness at, and in the vicinity of Phelps Spring.

Figure 1, of plate XI., is a profile section from the Grubb Cut, immediately northeast of the Southern mine property, to Phelps Spring, half a mile north of Cushman. The section runs from northeast to southwest and represents a distance of about three-quarters of a mile. It will be seen that at Phelps Spring the St. Clair limestone is in almost its full thickness, having decayed only slightly in its upper part and on the exposed slopes. Small deposits of ore-bearing clay have collected, as a result of this initial decay, in hollows in the limestone; and, in some places, the broken chert has been let down over the deposits, while in other places, as in the face of the hill overlooking the

* Sections of shafts at the Southern mine are given in plate X., chapter VIII.

spring, the clay is exposed without this protecting cover. Several pits have been sunk in the face of the hill and back on the ridge, but the deposits have been found to be of limited extent; yet, less than a mile to the northeast, at the Southern mine, the limestone has undergone a great amount of decay, and the resulting large deposits of ore-bearing clay are found. Still farther to the northeast, the St. Clair limestone again appears in considerable thickness, as shown in the right-hand end of the section; while beyond, in the same direction, there is an area of complete decay, which includes the region of the Turner mine, the Polk Southerd tract, and the Wren mine.*

Between the Phelps Spring and the Southern mine, there is an area of hills heavily covered with chert. In some places these run out in high ridges, in which the St. Clair limestone doubtless exists in considerable thickness under the chert covering, while elsewhere they sink to much lower ridges and knobs, such as are represented in the section. As nothing can be seen but an unbroken chert area in this intermediate distance, the interior of the hills, where either the remnant of the St. Clair limestone or its residual clay should be, is left vacant in the section. Judging from the elevation of the lower hills, however, the limestone must not only have largely decayed, but the thickness of the clay must be less than in the Southern Hill, otherwise the chert would not have sunk as low as it has. Many of the ravines in this area are doubtless hollows of erosion, partly filled with loose chert from the hilltops.

The Southern mine; mining and preparation of the ore.— The method of mining on the Southern Hill consists of a series of shafts with lateral drifts at desirable points. No machinery is used either in sinking or tunneling. Hoisting is done by hand windlasses or by "whips" worked by horses. Blasting is not always employed even in the chert, as that bed is so much shattered that shafts can sometimes be sunk through it with pick and shovel alone, but the use of dynamite is often necessary.

* The probable causes of this unequal decay in the limestone have already been explained in chapter VIII., pages 178-179, to which the reader is referred for further details.

The clay also can be worked with pick and shovel, but the employment of dynamite often hastens the work in loosening the bed and the masses of ore. Timbering is generally necessary, as the looseness of the chert bed and the tendency of the clay to cave in, render an unprotected shaft dangerous. The shafts are small and the timbering is cheaply done with roughly split logs. Frequently in wet weather the shafts are flooded with surface water, causing considerable expense and loss of time, but in fair weather few such difficulties are experienced.

The principle of work is to sink a shaft as cheaply as possible until a pocket of the ore is reached. After passing to the base of the ore, drifts are run out in various directions and the whole pocket removed. If, in drifting and sinking still farther, no more ore is found in the clay, the shaft is abandoned and a new one sunk elsewhere. The distribution of the pockets of ore is very irregular: sometimes they are separated laterally by several hundred feet of barren clay, and at other times they come almost in contact with each other. Experience is said to show that, as a result of this irregularity, the small shaft system is the cheapest, and that it pays better to sink a large number of small shafts than to drift aimlessly around underground in quest of a new pocket of ore. Many shafts have been sunk in search of such pockets, and a large number of them have been successful.

The method of mining by a large open cut has been tried at the Southern mine, but it proved a failure on account of the expense of removing the heavy capping of chert. Elsewhere in the region, however, where the chert is thinner, the open cut method can be advantageously employed, as will be explained in chapter XI.

After the ore has been mined, the larger masses are separated from the clay by hand and shipped without further preparation. This is known as "lump ore" The smaller ore and its associated clay, known as "wash dirt", contain from ten to twenty-five per cent of ore. The material is carted to a large receiving bin and thence carried on an inclined tramway to the washer, which is of the kind often used for iron ores. The manganese is first dumped into a long trough filled with running water. A

central shaft, armed with flanges arranged in the shape of a broken helix, revolves lengthwise in the trough, and gradually forces the ore to the other end. At the same time the beating and washing that the ore receives, frees it from most of the adhering clay. At the end of the trough the ore passes over a screen, and the larger pieces are taken up on an apron-belt and carried to the ore bin. A man stands by the apron to pick out the masses of rock and hard clay that are mixed with the ore. The ore that has passed through the screen is then sized by other screens and passed into jigs, where it is separated from the intermixed fragments of chert and from the clay that still adheres to it.

The most troublesome question at the Southern mine has been that of the water supply. The elevated position of the property renders it necessary to get water either by pumping from one of the streams in the lower country or by boring a well. A small spring rises on the slope of the hill, but its discharge is small. In 1887 and 1888 a well* was bored to a depth of two thousand and forty feet; and, though a large supply was not obtained, the water from it, with that saved from the spring by means of a dam, is now utilized to wash all the "ore dirt" that is mined. It is necessary, however, to be economical in the use of the water.

The ore is hauled in wagons to Cushman, and shipped thence to its destination by way of the St. Louis, Iron Mountain and Southern Railway. It is consumed principally by the Illinois Steel Company, of Chicago.

The Phelps tract.—The Phelps tract is in 14 N., 7 W., section 4, the southwest quarter. It belongs to the Keystone Manganese and Iron Company and is less than a mile southwest of the Southern Hill. It lies immediately north and east of Phelps Spring, and the character of the property, as well as its relation to the Southern Hill, is shown in the section in figure 1, plate XI. At the latter place the amount of decomposition that has gone on in the St. Clair limestone is large, and therefore the quantity of ore-bearing clay is large; but this decay is very irregular in its

* A section of the rocks passed through in this well-boring is given on page 118.

extent, and the Southern Hill is simply a local development of it. It will be seen by the section that in the hill immediately northeast of Phelps Spring, which is comprised in the Phelps tract, the St. Clair limestone exists in almost its original thickness, so that no large deposits of ore-bearing clay are to be expected.

On the sides of the ravines and hollows, local deposits of limited extent have doubtless been formed, and from these variable quantities of ore might be taken, but no such bed as that at the Southern Hill will be found. Several small pits have been sunk, in some of which ore has been discovered.

The Matt. Martin tract.—This part of the Martin property is in 14 N., 7 W., section 8, the northeast quarter of the northeast quarter, and adjoins the Phelps tract on the southwest. It is heavily capped with chert, and loose fragments of that rock cover the slopes. No mining has been done on the property, but occasionally large masses of ore are mixed with the loose chert on the hillsides. These ore masses are generally flat, as would be expected from their mode of derivation from lenticular layers in the St. Clair limestone. The hill on which the property is situated is much lower than the Phelps tract, and it is probable that the limestone beneath the chert has undergone a large amount of decomposition.

The presence of fragments of ore on the slopes of the hill proves that the original limestone contained manganese; the nature of the hill leads to the belief that a large part of the limestone has decayed; hence, as the presence of the manganese depends on these two conditions, there is a possibility of their being considerable quantities of ore on this tract.*

The Grubb Cut.—The Grubb Cut is in 14 N., 7 W., section 4, the southwest quarter of the northeast quarter. It adjoins the Southern mine and is the property of the St. Louis Manganese Company. The accompanying figure† shows a section across

*The other manganese-bearing tracts belonging to Colonel Matt. Martin, the owner of this property, are described in the order of their occurrence in the different localities.

† This figure has already been given and described in chapter VIII., page 195, in the discussion of the subsidence of the chert as a result of the decay of the underlying St. Clair limestone. It is given here again to facilitate the description of the property. A drawing of the opening at the Grubb Cut is also given in chapter VIII.

the main pit. At the base of the pit are two masses of St. Clair limestone of a gray color, which lie horizontally and represent

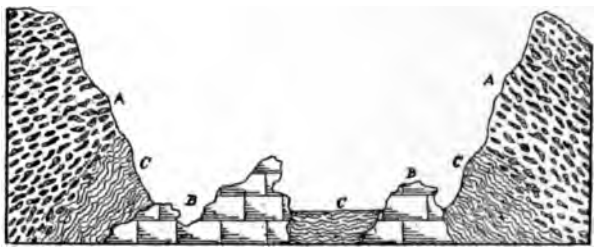


Figure 21. *Section through the Grubb Cut, one mile north of Cushman, showing the decay of the St. Clair limestone, the formation of residual manganese-bearing clay, and the subsidence and tilting of the overlying Boone chert.*

A. Boone chert.
B. St. Clair limestone.
C. Manganese-bearing clay.
Horizontal and vertical scale: 1 inch — 80 feet.

parts of the formation that have survived decomposition. Surrounding and overlaying them is the manganese-bearing clay, overlain in turn by from one to twenty feet of chert.

Captain Ed. Wilburn, Superintendent of the St. Louis Manganese Company's mines, states that two shafts, now mostly filled up, were sunk here. One was thirty feet deep and was in the clay bed all the way; the other was forty feet deep and was sunk in the bottom of a tunnel which was itself forty-five feet below the surface.

As will be seen in the figure, both the clay bed and the chert dip away from the underlying bodies of limestone, covering them in the form of a rough cone and pitching off from them in all directions. The position of the chert and clay is the natural result of their sinking over the unevenly decomposed surface of the limestone, as explained in chapter VIII. The chert is much shattered and broken, and near the clay bed it is deeply stained with manganese. The clay contains manganese in both large masses ("lump ore") and small masses ("wash dirt").

The Turner mine.—The Turner mine is in 14 N., 7 W., section 3, the northeast quarter of the northwest quarter, and is situated at the head waters of Turner Creek, half a mile northeast of the Southern mine. Something over 4,000

tons of ore are said to have been taken from the property, of which quantity from 500 to 1,000 tons were mined by E. H. Woodward and Company, and the rest by the Keystone Manganese and Iron Company at different times between 1886 and 1890.

The ore is associated with red clay and directly overlies the decomposed surface of the Izard limestone. It is capped by the broken and disturbed remains of the chert bed, which varies from only a few scattered fragments to twenty feet in thickness. The St. Clair limestone has entirely decayed, and the clay and ore remain as the residual product. Even the Izard limestone, which once formed the base on which the St. Clair limestone rested, has been attacked by the surface waters, and deep hollows, separated by protruding knobs, have been formed in its surface. The ore-bearing clay has collected in these hollows and also covers the protruding knobs. A large part of the northern end of the hill has been excavated, and the rugged floor of Izard limestone has been exposed.

The accompanying drawing, plate XVI., represents a view in one of the openings on this property. The masses of rock in the center and on the extreme left-hand side are partly disintegrated bodies of Izard limestone, protruding in the form of irregular knobs from the main mass of that formation below. They are surrounded and covered by the manganese-bearing clay, which forms the rest of the hill represented in the drawing. Numerous fragments of chert, from the upper part of the clay bed, have rolled down and are mixed with loose pieces of limestone and masses of manganese ore on the slopes of the excavation.

The drawing illustrates a typical case of the conditions which exist in places where the St. Clair limestone, when highly charged with materials to form deposits of ore-bearing clay, has completely decayed; and where the underlying Izard limestone has partly decayed, and holds the residual products of the overlying formation in the hollows on its surface. Practically the whole of the ore-bearing

THE TURNER MINE, BATESVILLE REGION, ARKANSAS.

clay represented in the drawing has come from the St. Clair limestone, since the Izard limestone contains no manganese ore and only very little insoluble material to form a clay bed when decomposed. Occasionally the chert has partly disintegrated into a fine powder, which may increase the bulk of the clay to a limited extent; but the addition is very small.

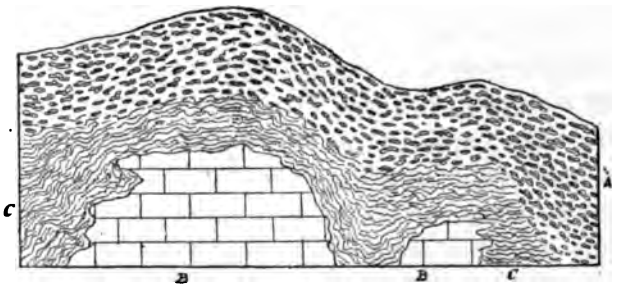


Figure 22. *Section at the Turner mine showing the manganese-bearing clay overlain by chert and occupying hollows in the decomposed surface of the Izard limestone.*

A. Boone chert.
B. Izard limestone.
C. Manganese-bearing clay.
Horizontal and vertical scale: 1 inch—25 feet.

The accompanying figure 22 is a section near the view represented in the last drawing. It illustrates the same subject, except that here the chert bed is shown above the ore-bearing clay. It will be observed that the clay overlies the irregularly decomposed Izard limestone; that the chert has been let down on the clay in a broken mass of varying thickness; and that the contour of the surface of the hill is largely influenced by the position of the protruding knobs of limestone below.

As would be expected in a deposit such as the one at the Turner mine, the thickness of the clay is very changeable, varying from four to forty feet or more. The bed is not so thick as in places like the Southern mine where even less decay of the St. Clair limestone has gone on. In the parts of the Turner property where the chert has been almost entirely removed, this difference in the thickness of the clay may be due to erosion by surface waters, but it is probably due mostly

to the fact that the original limestone did not contain the material to form a thicker bed. The value of a deposit, however, does not depend alone upon the thickness of the ore-bearing clay, but on the percentage of the ore in that clay; and it often happens that a clay of great thickness does not contain a paying quantity of ore, while a much thinner bed may pay well. It is necessary, therefore, to make a special study of each locality in order to determine its value. The Turner mine is a case where a comparatively thin bed of clay contains large quantities of ore.

The Polk Southerd tract.—The Polk Southerd tract is in 14 N., 7 W., section 3, in the northwest quarter of the northwest quarter, and is the property of Col. Matt. Martin, of Batesville. No extensive work has been done on it, although a few small openings have been made, from which 114 tons of ore are said to have been taken.

The property adjoins the Turner mine on the west and forms a part of the same hill. What has been said of the occurrence of the ore at that mine applies equally to this tract. The chert is thin and often occurs only as loose fragments. In the latter case it is deeply stained with manganese and mixed with masses of ore. There are probably considerable quantities of ore on this property.

The Wren mine.—The Wren mine is in 14 N., 7 W., section 4, and comprises a portion of the northeast quarter. It is the property of the St. Louis Manganese Company. A number of pits show the presence of manganese ore in varying quantities, associated with red clay and overlain by from two to eight feet or more of loose chert. The St. Clair limestone is not seen in place, but fragments of it are occasionally found in the clay, proving its former existence in this locality. The ore-bearing clay overlies the uneven surface of the Izard limestone, filling holes and basins, and covering knobs of that rock. Some of the cavities doubtless extend to considerable depths and contain a variable amount of ore. Here, as at the Polk Southerd tract and the Turner mine, the ore-bearing clay represents

the residue from the complete decomposition of the St. Clair limestone.

The Lapham mine.—The Lapham mine is in 15 N., 7 W., the south half of section 33. It is the property of the St. Louis Manganese Company, and considerable mining has been done on it. It is mostly covered with chert, but the red "ore dirt" has been found under this at a depth of from six to twenty feet. A shaft has been sunk into the "ore dirt" for thirty-nine feet without reaching the underlying rock. At the bottom of the shaft a drift was run out to the northwest slope of the hill, a distance of a hundred and eighteen feet. The clay bed is continuous for the whole of this distance, and in many places contains manganese ore. Numerous masses of St. Clair and Izard limestone, varying from one to ten feet in diameter, as well as the usual amount of chert fragments occur in the clay. As a result of the considerable amount of decay which has taken place on this property, and also of the fact that the ore deposit has been protected by the chert covering, an extensive deposit of clay with pockets of ore of different sizes may be expected.

The Thomas Cecil tract.—The Thomas Cecil tract is in 14 N., 7 W., section 5, the west half of the northwest quarter. It is three miles northwest of Cushman, on the hills lying east of East Lafferty Creek and south of Turner Creek. With the exception of a few prospect openings, no work has been done on it. The hill on which the property is situated is capped by about thirty feet of chert, loose fragments of which, associated with occasional fragments of St. Clair limestone and small masses of manganese ore, cover the slopes. A large part of the St. Clair limestone doubtless remains in the interior of the hill, and consequently the deposit of ore-bearing clay, which is derived directly from the decomposition of this rock, is not so thick as if more of it had decayed. Pockets of clay, however, containing more or less ore, will doubtless be found at various places on the slopes.

The W. H. Cole tract.—The W. H. Cole tract is in 14 N., 7 W., section 6, the southwest quarter of the northeast quarter; and the northwest quarter of the southeast quarter. It lies on

the south side of Turner Creek, two and a half miles northwest of Cushman. Several small pits which have been dug show the presence of manganese ore in a red clay. The deposit is said to have been sunk into for twenty-five feet without reaching the bottom of the clay. The ore is of a hard, dark iron-gray variety and often contains numerous cavities filled with earthy matter.

Fragments of St. Clair limestone, of a chocolate-brown color, are frequently found in the clay, and it is probable that the main body of that rock still underlies the deposit, which is not so thick as it would have been had more of the limestone decayed. The clay bed, however, probably has a considerable lateral extent.

Similar ore under similar conditions occurs on the lands of John Cole and of Jake Cole, adjoining this property.

The following tracts in this neighborhood are also owned and held as ore-bearing lands by members of the Cole family:

14 N., 7 W., section 6, the southwest quarter; and the east half of the southeast quarter; section 7, the northwest quarter of the northwest quarter; the northeast quarter of the northeast quarter; and the northwest quarter of the southwest quarter. These properties have not been examined by the Survey. Several other similar tracts are also owned by the Cole family.

LAFFERTY CREEK BASIN.—*Upper part of the East Lafferty Creek region.*

General features.—North of the Turner Creek basin, up the valley of East Lafferty and the east side of Middle Lafferty Creeks, in 15 N., 7 W., the St. Clair limestone entirely disappears, with the exception of a few small outcrops in the southeast part of the township. The ore-bearing clay, resulting from the decomposition of this rock, occupies the upper parts of isolated hills of Izard limestone, and is sometimes capped by rugged knobs of chert, at other times by only a few scattered fragments of that material. The lower country is composed partly of the sandstone that underlies the Izard limestone, and the area covered by it becomes more and more extensive, until

Barren Fork is reached, where the sandstone almost entirely replaces the other rocks.

The manganese-bearing clay, in many places where the chert capping has been removed, has suffered considerably from the action of weathering and has often become thin; but, in some places, it still preserves a considerable thickness and fills deep holes in the Izard limestone.

Manganese under these conditions of occurrence is found in many places between Turner Creek and Barren Fork, among others in 15 N., 7 W., sections 20, 21, 28, and 29, on the land of Messrs. Williamson, Luster, Dr. Dobson, and others. Little or no mining has been done in this region, however, and but few practical tests of the deposits have been made. On the land of Mr. R. P. Williamson, in 15 N., 7 W., section 21, the northeast quarter of the southwest quarter, manganese ore is found overlying the Izard limestone, and associated with red clay and loose fragments of chert.

Manganese occurs in small quantities in the neighborhood of, and north of Barren Fork, on the lands of Messrs. Rudolph, Albright, Holland, and others. At Barren Fork, however, the ore-bearing deposit, if it ever existed in any considerable thickness, has been almost entirely removed, and the ore occurs only in small isolated patches of red clay, lying on the surface of the Izard limestone or the underlying sandstone.

The Peter Reeves tract.—The Peter Reeves tract is in 15 N., 7 W., section 8, the south half of the southwest quarter, and is a mile northwest of Barren Fork, near the head waters of Middle Lafferty Creek. A crystalline, black ore, associated with the usual red clay, covers the top of a limestone hill on this property, and the only remains of a chert bed are a few scattered fragments on the surface. The hill is cultivated and numerous masses of ore have been plowed up.

The ore-bearing clay, being unprotected by a covering of chert, has been exposed to erosion, and a portion of it has been carried away, but it is probable that a considerable quantity of it still remains in the hollows in the Izard limestone.

This property may be considered as the extreme northern

limit of the manganese in the valleys of East and Middle Lafferty Creeks. Ore has been found in small quantities in association with red clay elsewhere to the north, but it occurs only as occasional, small, scattered masses of no commercial importance.

Mr. Reeves also owns 15 N., 7 W., section 17, the northwest quarter of the northwest quarter.

LAFFERTY CREEK BASIN.—*The divide between West Lafferty and the waters of Middle and East Lafferty Creeks.*

General features.—The divide between the waters of West Lafferty Creek and those of Middle and East Lafferty is a well known topographic division of the manganese region, and for this reason, as well as for convenience in description, it is treated separately. It begins at the confluence of the two main forks of Lafferty Creek, a mile above the White River, and extends north to the head waters of Middle Lafferty, two miles northwest of Barren Fork. It is over eight miles in length and from one to three miles in width, the broadest part being near its northern extremity. The general features of the divide are similar to those of the country just described, and change in the same way going north.

The southern part of this area is a high region heavily covered with chert, and represents one of the most rugged parts of the Lafferty Creek basin. The St. Clair limestone has only partially decayed, and the deposits of residual clay which have resulted from this decay, though they sometimes contain ore, are not so deep as if more of the limestone had been decomposed. To the north, the decomposition of the limestone becomes more and more marked, until all that remains are the deposits of residual ore and clay. The chert, in this direction, has also suffered from erosion, and in many places has been almost entirely removed. Consequently the ore-bearing clay is exposed to the action of the weather, and, still further north, it becomes thin and finally disappears altogether.

The George tract.—The George tract is in 14 N., 8 W., section 11, the southwest quarter of the northeast quarter; the west half of the southeast quarter; and the northeast quarter of the

southeast quarter. It belongs to the Keystone Manganese and Iron Company, and is situated less than a mile above the confluence of the two main branches of Lafferty Creek. A few small pits have been sunk on the top of a hill, and show the presence of manganese ore associated with red clay. A hundred and ninety-three tons of ore are said to have been taken from this property.

The clay deposit is covered by from ten to forty feet or even more of chert. Numerous masses of St. Clair limestone are associated with the ore, and the main body of the limestone is exposed on the hillsides in the vicinity. The amount of decomposition of that bed is thus shown to have been comparatively small, and the deposits of ore-bearing clay, at least in the part of the property where work has been done, will generally be found to be limited in depth as well as in lateral extent.

The Crosby tract.—The Crosby tract is in 14 N., 8 W., section 2, the north half of the southeast quarter. It is less than a mile north of the George property, and manganese is found on it under nearly the same conditions as at that place. The summit of the hill is capped by about thirty feet of chert. The St. Clair limestone is exposed in ledges at various places on the slopes and in small pits on the summit. It is of a dark chocolate color and frequently contains manganese ore in nodules or small seams. It has been partly decomposed, and, as a result, pockets of clay and ore have formed. Several small pits which have been sunk in these beds show them to be somewhat limited in extent, but often rich in manganese. The clay is of the same dark brown color as that of the limestone from which it was derived.

The Crosby property illustrates the partial decomposition of a bed of St. Clair limestone highly charged with manganese and argillaceous matter; and, in spite of the limited decay, there was sufficient of these materials in the bed in this locality to form the present deposits of ore.

The Gregory tract.—The Gregory tract is in 14 N., 8 W., section 2, the southwest quarter of the northeast quarter; and the southeast quarter of the northwest quarter. It belongs to the Keystone Manganese and Iron Company and adjoins the Crosby

property. It is a part of the same range of hills as the latter place, and what has been said of that applies equally well to this. Several small pits which have been sunk show the presence of manganese ore, associated with red and brown clay, overlying the decayed surface of the St. Clair limestone. Twenty-five tons of ore are said to have been taken from the property.

The thickness of the St. Clair limestone on this tract is about fifty feet. Its thickness in the surrounding region, where it is unaffected by leaching, is over a hundred feet. Therefore at least half of it has probably decayed, and the ore and clay, lying in the hollows, have been derived by this decomposition. The rock varies from pink to a dark brown color and often contains nodules and thin seams of ore.

The William Martin tract.—The William Martin tract is in 14 N., 8 W., section 2, the east half of the southwest quarter of the southwest quarter. It belongs to the Missouri Furnace Company, and several large openings have been made on different parts of the property. The hill on which it is situated is capped with about forty feet of chert, beneath which the St. Clair limestone is deeply scored with holes and basins carrying the ore-bearing clay. These hollows are seen on the slopes and probably extend back into the hill under the chert. The clay is of a red or dark chocolate-brown color and contains masses of ore, of a hard, steel-gray, crystalline variety, varying in size from small particles to lumps weighing a hundred pounds or more. Frequently loose masses of St. Clair limestone, from one to twenty feet in diameter, are found in the clay, and represent parts of the bed that have not yet been decomposed. These vary from gray to dark brown in color, and contain seams and masses of ore of the same kind as that found in the clay, and from half an inch to six inches in thickness. The seams are lenticular and very irregular. They protrude from the weathered surface of the limestone, and, in the words of the miners, they are said to be "welded on to the rock"; whereas, it is just the opposite action that has gone on: the limestone that encloses the ore is being gradually dissolved, and the harder

masses of ore, resisting the dissolving action more successfully than the limestone, remain, and are being slowly set free from the rock. A drawing of one of these limestone masses is given in chapter VIII., and described on page 168.

This property furnishes an excellent example of the derivation of manganese deposits in this region. The ore and clay once formed a part of the St. Clair limestone; the clay was scattered through the rock and the darker varieties of it have given the limestone its dark color; the ore occurred in masses and seams in the original rock, in the same way that it is now seen in the loose masses of limestone in the clay. Surface waters attacked the bed, dissolved the carbonate of lime, and left the clay and ore as they are now found. The ore-bearing part of the St. Clair limestone was both overlain and underlain by parts of the same formation without ore.

To the north of this region, the St. Clair limestone becomes thinner and finally disappears, the only remains of it being the deposits of ore-bearing clay. These are exposed on isolated hills and ridges composed largely of Izard limestone, and underlain by the saccharoidal sandstone. Sometimes a part of the ore-bearing clay is capped by a small knob of chert, but this rock has also become thin and is often represented by only a few scattered fragments on the surface of the clay.

The Reuben Rogers tract.—Mr. Rogers owns several tracts of land in 15 N., 8 W. One of them visited by the Survey, is situated on a hill rising about a hundred feet above the surrounding drainage. The summit of the hill is capped by about twenty feet of chert, and the red ore-bearing clay is exposed on the slopes of the Izard limestone below. No mining has been done, but the ore is seen in loose masses on the hillsides, and has frequently collected in the gullies that have cut their way into the clay.

The Thomas Nail tract.—The Thomas Nail tract is in 15 N., 8 W., section 36, the west half of the northwest quarter of the northwest quarter. Manganese is found here under

the same conditions as at the last mentioned places. A few loose fragments of ore are on the surface, but no mining has been done.

Mr. Nail also holds as ore land 15 N., 8 W., section 36, the northeast quarter of the northwest quarter, but this place has not been examined by the Survey.

Manganese ore, under conditions similar to those existing on the Nail tract, occurs on the land of John Rogers in 15 N., 8 W., section 34, the north half of the northeast quarter; on the land of Ephraim Sipes in 15 N., 8 W., section 25, the southwest quarter of the southwest quarter; on the land of James Blue in 15 N., 8 W., section 13; and at other places in the neighborhood. Little or no mining has been done on these properties, and a few small prospecting pits are all that exist to show the nature of the deposits.

The William S. Nail tract.—The William S. Nail tract is in 15 N., 8 W., section 25, the southeast quarter of the northwest quarter. It differs from other places described in the vicinity in that a part of the original St. Clair limestone is still preserved. The chert bed has been almost entirely removed, the only remains of it being a few scattered fragments on the top and slopes of the hill. The St. Clair limestone varies from five to twenty-five feet in thickness, and caps the top of a narrow ridge. It contains interbedded strata of a fine grained sandstone sometimes carrying small, flat, concretions of ore. The Izard limestone crops out below the St. Clair limestone with a thickness of about a hundred and forty feet, and is underlain at the foot of the hill by the saccharoidal sandstone. The small exposure of St. Clair limestone seen here represents the remains of a bed once, probably, a hundred feet or more in thickness.

The ridge slopes off almost perpendicularly on the northeast side and the rocks are exposed in bare ledges; but on the southwest, the slope is much more gradual, and here the ore-bearing clay has collected. In some places it overlies the St. Clair limestone in small hollows, but most of it has been washed down the slopes of the hill and overlies

the Izard limestone. No mining has been done on the property.

Other localities on the divide between West Lafferty and the waters of Middle and East Lafferty Creeks.—For a distance of two miles north of the William S. Nail tract, manganese is found at various places. On the land of Mr. McSpadden, 15 N., 8 W., section 13, the east half of the southwest quarter, the red clay with manganese ore and fragments of chert, occurs on the top and slopes of a hill. Similar deposits are seen on the lands of Mr. Tingle and others between here and Barren Fork, as well as on the property of Peter Reeves already described, though little or no mining has been done in this neighborhood. Fragments of ore also occur on the land of Nick Moser, 15 N., 8 W., section 11, the northeast quarter, but this locality is at the northern limit of the manganese region, and the ore has already become much scattered. Beyond, it entirely disappears, with the exception of small pieces occasionally found on isolated outliers of Izard limestone.

LAFFERTY CREEK BASIN.—*The west side of West Lafferty Creek.*

General features.—Manganese ore has been found in several places, on the waters draining into the Lafferty Creek basin from the west and northwest, especially in the region northeast of Penter's Bluff. The general features of the country are the same as those already described in the part of the Lafferty Creek basin to the east, and do not require further mention. Very little mining has been done, and a few small pits represent the whole of the work in this area.

*Penter's Bluff.**—Penter's Bluff is in 14 N., 8 W., section 9. It is an almost vertical cliff, skirting the northeast side of the White River for a mile, and commencing, at its lower end, about a mile above the mouth of Lafferty Creek. It reaches a maximum height of four hundred and eighty-five feet (baro-

* The name Penter's Bluff is variously misspelled. Among the most common corruptions are "Painter's," "Pinter's," "Pander's," "Pendar's" Bluff. The bluff is said to have received its name from a family of early settlers named Penter, and therefore the spelling Penter's Bluff is the only proper one.

metric measurement) and is one of the best known landmarks on the river, rising up in bold contrast with the more gently sloping hills in the background. At its upper and lower ends, it slopes off rapidly to the level of the river. The bluff is on the outward side of the bend of the river where the latter turns from an easterly to a southerly course. A profile view of Penter's Bluff, where it abuts on the White River, is given in the frontispiece of this volume.

Penter's Bluff is the property of Colonel Matt. Martin, of Batesville, and adjacent to it is a steamboat landing from which the first shipments of manganese from this region, about forty years ago (1850-1852), were made. (See page 104.) The White River can usually be navigated up as far as Penter's Bluff by good sized steamers for eight months out of the year, and small steamers can reach the bluff at almost all times of the year.

In the face of the bluff are seen good exposures of the St. Clair and Izard limestones, capped by the Boone chert. The chert bed has been eroded to a considerable extent and is only about fifty feet in thickness. This erosion, however, is local, and to the northwest the bed regains most of its original thickness. On the top of the bluff it is interstratified with seams of crystalline limestone. The St. Clair limestone or marble* is exposed immediately below the chert in the more than average thickness of a hundred and fifty-five feet, and, except superficially, has not suffered from the decomposing influences that have acted on it to the north. Consequently no collections of manganese-bearing clay have been found immediately on the bluff, but occasionally a few fragments of ore have been weathered out of the rock, and are seen in association with the loose masses of chert that cover the slopes at the north and south ends of the bluff. In one place, a mass of ore six inches thick, one foot wide, and one foot long, was seen attached to a loose block of St. Clair limestone. A short distance back of the bluff, however, the limestone has been partly decomposed and more ore has been found

* Penter's Bluff is well adapted as a point for quarrying and shipping this marble. See report of T. C. Hopkins on Marbles and Other Limestones, annual report of the Geological Survey, 1890.

The underlying Izard limestone has a greater thickness at Penter's Bluff than at any other place observed in the manganese region. It forms the lower two hundred and eighty feet of the bluff, and as it is still seen at the base of the bluff, it is probably thicker. The greatest thickness observed elsewhere is at Lee's Mountain and the Southern mine, at both of which places it is two hundred and forty feet. The face of the limestone in the bluff shows an undulating dip of 3° to 5° to the east and southeast, and often contains hollows and caves. The upper part of the bed shows the smooth, even-grained limestone with a conchoidal fracture that has been mined elsewhere for lithographic stone. (See page 122.)

The Anderson Mill tract.—The Anderson Mill tract is in 15 N., 8 W., section 34, the southeast quarter of the southeast quarter, and on the west side of West Lafferty Creek, about two miles northeast of Penter's Bluff. The property forms a bluff immediately west of West Lafferty Creek, and is heavily capped with chert, below which the underlying beds are successively exposed on the hillsides. Manganese in association with the usual red and brown clay, overlies the decayed surface of the St. Clair limestone, and has often been washed down over the Izard limestone slopes below. Mr. C. F. Drake is said to have mined several car-loads of ore on this property in 1890.

The Ruminer tract.—The Ruminer tract is in 15 N., 8 W., section 34, the northeast quarter of the southeast quarter, and adjoins the last property on the north, forming part of the same range of hills. No mining has been done, but scattered fragments of manganese ore are found on the surface. The chert has been almost entirely removed, and the top of the hill is covered by a remnant of the St. Clair limestone, fifty feet in thickness. Below this are successively exposed the Izard limestone and its underlying sandstone.

The hill rises a hundred and fifty feet above a small creek at its base and the St. Clair limestone can be traced along it for a mile. It is of a gray or pink color, granular on the surface, and much disintegrated. The manganese ore and its associated clay, which have resulted from the

decomposition of this rock, occur in small basins on its surface, and where those materials have been washed from above, they are found on the slopes of the underlying Izard limestone.

The Ruminer property also includes 15 N., 8 W., section 34, the northwest quarter of the southeast quarter; and the southeast quarter of the northwest quarter.

THE WILSON HILLS.

General features.—The area north of the White River and immediately west of the waters of the Lafferty Creek basin is known as the Wilson Hills. It is a high, rugged region, rising four to five hundred feet above the White River, and extending east and west around the head waters of Wilson Creek. The higher elevations are heavily covered with chert, through which deep ravines, exposing the underlying St. Clair and Izard limestones, have been cut by numerous creeks running south into the White River. Large springs are a marked feature of such ravines, and frequently the rushing of underground waters can be heard at their mouths.

This chert-covered region extends from the White River northward for six miles, and finally ends abruptly in Lee's Mountain. Beyond this, the country is underlain almost entirely by the sandstones and limestones that bound the manganese region on the north.

Absence of manganese in the Wilson Hills.—Very little manganese has been found in the Wilson Hills. Occasionally small pieces occur, but even these are rare and, so far as is yet known, no deposit of commercial value has been discovered. The St. Clair limestone is exposed on many of the creeks running south into the White River, and occasionally on the northern slopes of some of the hills. It has had abundant opportunity for decay, and often it has been decomposed to a considerable extent. Consequently, if the bed had contained the materials necessary to form deposits of ore-bearing clay, as has been explained in chapter VIII., the lat-

ter would be seen in some places at least. Thus, on Lee's Mountain, in 15 N., 8 W., section 7, there remains a thickness of only forty-five feet of the original limestone which, where it occurs in its full thickness in the neighborhood, varies from a hundred to considerably over a hundred feet; yet no trace of either residual clay or manganese ore is seen. In many places the absence of these materials might be due to the removal by erosion of both the ore and the clay, but in others, the conditions are just as favorable for their preservation as in the manganese region to the east. The same decomposition of the St. Clair limestone is seen in places on Wilson Creek, and yet the only traces of ore are a few scattered fragments.

Consequently it is evident that the absence of manganese ore and its associated red clay in the country west of the manganese region, is due to the absence from the St. Clair limestone in that area of the materials necessary to form such deposits. This supposition is still further strengthened by the fact that in that region, manganese is not seen in place in the original limestone as it often is to the east. The rock is generally of a light gray color and, though a chemical test of it often shows a trace of manganese, this material does not occur in visible quantities, as is frequently the case in the Lafferty Creek and Polk Bayou basins. In the latter places, as already described, the limestone not only often contains manganese in layers and masses, but is sometimes impregnated with it throughout, in the form of fine clay, which gives the rock a dark chocolate-brown color.

The purity of the limestone in the Wilson Hills region not only accounts for the absence of the ore, but also for the absence of the red or brown clay such as occurs elsewhere with the ore; since the purer the limestone the less the amount of insoluble residue (clay) that will be left when the rock decays. (See pages 188-189.)

STONE COUNTY.

General features.—The White River, in the region both above and below Penter's Bluff, marks the boundary line

between Stone county on the south and west, and Independence and Izard counties on the north and east. In this part of Stone county the same rocks are seen as those already described on the opposite side of the river, though they do not occur in such steep cliffs as at Penter's Bluff.* The hills are heavily capped with chert, and on their slopes the St. Clair and Izard limestones are successively exposed. Manganese has been found in small quantities in several places in this region, but only a little prospecting has been done and no ore has been shipped. The ore occurs in association with red clay, and lies in the hollows on the slopes of the St. Clair limestone; but this rock has been only locally decomposed, often retaining its whole thickness, and therefore the deposits of ore-bearing clay are small. Outside of the part of Stone county marked on the map as being in the manganese region, small quantities of ore have been found in isolated localities. Among these is the Foster tract.

The A. T. Foster tract.—The A. T. Foster tract is in 15 N., 9 W., the north part of section 34. It is two and a half miles west of the western limit of the region represented in the map accompanying this volume, and on Dry Creek, a tributary running north from the Boston Mountains into the White River. Fragments of a hard, massive, black manganese ore have been found in association with a red clay, lying in cavities on the surface of the St. Clair limestone, as shown in the accompanying figure. Two small pits have been dug, but no ore has been shipped.

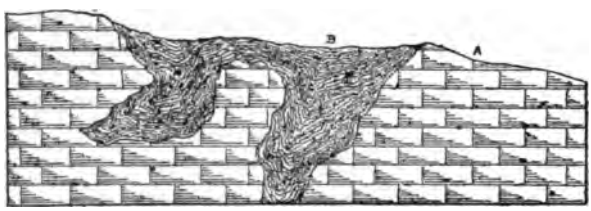


Figure 23. *Section on the A. T. Foster tract, showing the formation of manganese-bearing clay by the decay of the St. Clair limestone.*

A. St. Clair limestone.

B. Manganese-bearing clay.

Horizontal and vertical scale: 1 inch = 6 feet.

*See profile section, figure 3, of plate XI.

The figure illustrates the dissolving action of surface waters on the limestone. They have gradually removed the carbonate of lime in the limestone, while the clay and ore, which were once distributed through that rock, have collected in the hollows thus formed. Fragments of ore are also seen on the slopes of the hill in several other places.

Limits of the manganese region on the west.—West of the last mentioned locality, the St. Clair limestone and the associated chert and Izard limestone are exposed in an almost continuous series of outcrops. These extend from the region shown in the map accompanying this volume, in a westerly direction to the western part of Searcy county, a distance of about sixty miles from the West Lafferty Creek basin, where the St. Clair limestone thins out. (See pages 125 and 172.) Manganese has been reported in several places in this area, among others near Sylamore, in Stone county. Such localities, however, are isolated areas, and, as a rule, manganese does not characterize the region as it does the Lafferty Creek and Polk Bayou basins. The reason for this is doubtless the same as that explained in the case of the Wilson Hills.

It has already been shown that the ore-bearing part of the limestone ends on the east, in the region of Hickory Valley, in the same way that it does to the west of the Lafferty Creek basin. The Batesville region, therefore, represents an isolated accumulation in the St. Clair limestone of materials suited for the formation of ore-bearing clay. It is cut off on the east and west by a limestone, which is of the same general character, occupies the same geologic position, and represents the lateral extension of the ore-bearing limestone, but yet is destitute of the materials necessary to form ore-bearing deposits. To the north of the Batesville region, the St. Clair limestone disappears in the area of underlying Silurian limestones and sandstones; to the south, it dips under the Lower Carboniferous Boone chert.

CHAPTER XI.

THE BATESVILLE REGION OF ARKASAS—*Concluded.*

METHODS OF MINING IN THE BATESVILLE REGION.

Nature of the deposit to be mined.—The question to be dealt with in the Batesville region is that of mining an ore irregularly distributed, in nodules or pockets, through all parts of a clay bed from 20 to over 100 feet in thickness. The clay deposit is sometimes capped by from 5 to 60 feet of broken chert, and at other times it is exposed on the surface with only a few scattered chert fragments in its upper part. The deposit generally occupies the summits or higher slopes of abrupt hills, and overlies an uneven floor of limestone, often running down into it in deep holes. The manner of distribution of the manganese in the clay varies greatly: it is either in nodules scattered throughout the bed, or in irregular pockets of nodules separated by uncertain distances of barren clay, or in solid bodies thinning out on all sides and appearing again in a similar position at a greater or less distance.

It is characteristic of manganese deposits, not only in Arkansas but elsewhere, that hardly any two localities possess the same features, and this peculiarity has given them a reputation for uncertainty and irregularity. With an intelligent preliminary investigation, however, by boring or by sinking prospect shafts, it is perfectly possible to determine whether or not a property can be worked at a profit.

In order to mine profitably in the region in question, it is necessary to have a thorough understanding of the nature of the deposit in each special locality. The character of the ore and its enclosing material, its mode of distribution in this matrix, the depth of the ore-bearing deposit, the surface character of the

property, the water supply, the facilities for transportation, and, in fact, every feature of the subject that will in any way have a bearing on the mining and shipping of the ore, should be carefully studied before any operations are started; and no machinery or other expensive equipment should be brought on to the property, until all the local peculiarities of the deposit to be worked are known.

Methods of operating that can be applied in one locality cannot always be applied in another, and a lack of appreciation of the importance of this fact has undoubtedly been the cause of failure in many cases. In places where the capping of chert is heavy, underground work is often necessary, but where the chert is thin, or only in scattered masses, operations can be more cheaply carried on in open cuts. In places where there is a large quantity of small ore ("wash dirt"), a washer is absolutely necessary; where most of the ore occurs in larger masses, this expense can be avoided. There is always some "wash dirt" with almost all the ore in the Batesville region, but in many places it is not in sufficient quantities to pay for the expense of erecting and running a washer; while in other places, the success or failure of a property depends on having this means of cleansing the large quantities of small ore that occur.

It only too often happens that, in the first enthusiasm aroused on the opening of a new mine, an unwarranted amount of extravagance is practiced, and most of the working capital is expended in erecting fine buildings, purchasing unnecessary machinery, and in other surface equipment, totally regardless of the fact that a large part of that capital will be needed in the actual mining of the ore. Many companies, therefore, in possession of valuable mining properties, are often crippled at the very outset by having the part of their capital which should be devoted to actual mining, tied up in unnecessary surface expenditures. The average market value of any one of the base metals is generally but little above the cost of mining and transportation. Competition has entered into the art of supplying the world with metals as well as into every other industry, and many mines, giving large returns under skillful management, work on a very small

margin of profit. The success or failure of a property, therefore, depends largely on the management, and on a clear distinction between the equipment that is necessary for the proper working of a mine, and the equipment that is superfluous.

Present methods of mining.—The only systematic mining that has been done in the Batesville region is on the properties of the Keystone Manganese and Iron Company, of the St. Louis Manganese Company, and of John B. Skinner and Company, besides that formerly done by E. H. Woodward and Company. With the exception of these workings, all the rest of the mining consists of small pits and prospect holes.

The method of mining on the Keystone Company's property, as described on pages 267–269, consists of a number of small shafts, with short drifts at suitable points. Vertical shafts are sunk until a pocket of ore is found, and then drifts from 5 to 10 feet in length are run to allow the removal of the whole body of ore. When a pocket has been exhausted, and small extensions of the shaft and drifts do not reveal the presence of more ore, the place is deserted and a shaft sunk elsewhere.

On the properties of the St. Louis Manganese Company, the system of shafts and drifts has also been employed, but drifting and tunneling have been carried out on a more extensive scale. At the Brooks mine a tunnel 150 feet long has been run into the red clay, and at the Lapham property a similar tunnel 118 feet long has been made.

Open pits.—An open pit has been tried at the Southern mine but without success. The reason given for its failure is that the expense of moving the heavy covering of from 30 to 60 feet of chert, which overlies the ore-bearing clay, consumed all the profits from the ore mined. This is a strong argument and doubtless holds good on this property, but in places where the superficial covering of chert is thin, or where, as is often the case, especially in the northern part of the manganese region, the chert is represented only by loose fragments scattered over the surface, mining in large open pits will undoubtedly prove to be the cheapest method.

In deposits of the kind in question, where the ore is irreg-

ularly scattered through the clay, there is much risk of the bodies of ore being missed by a system of shafts and drifts, while a large open pit, which removes the whole bed, is sure to reveal everything in it. An argument against the open pit practice has been that it requires the removal of a much greater number of cubic yards of waste material per ton of ore, than the shaft and tunnel method. This is undoubtedly true, but the greater cheapness with which the clay can be handled in open cuts, much more than counterbalances the cost of moving the additional material.

In shafting and tunneling, it is generally necessary to timber, as the clay is apt to cave in. It is also necessary, if extensive work is done, to have underground tramways, lights, and all the other expensive requirements of underground mining. In large open pits none of these things are necessary.

In the small shafts and tunnels such as are often made, the miners are necessarily cramped and do not accomplish such effective work as if they had plenty of room. The usual method of hoisting from a shaft by a hand windlass is also much more expensive than hoisting with a derrick from an open pit; since, in the latter case, work in the pit can be so arranged as to keep the derrick going all the time, thereby greatly reducing the expense of hoisting; while in the case of a small, cramped shaft, only a limited number of men can work, the bucket moves up only at long intervals, and the two men at the windlass are idle a large part of the time, thereby adding greatly to the expense per cubic yard of material hoisted. It might be said that steam hoists or derricks could be used in the shafts, but the temporary character of the latter would not admit of steam hoists, and the slow rate at which the ground is moved in the small shafts would not pay for the expense of derricks. An argument frequently brought against the use of large open pits is that it injures the property for underground work, if that method of mining should prove desirable later on. This is true only in regions where work is being carried on in a deposit extending to a great depth; but in the Batesville region, the largest dimensions of the ore-bearing clay

are lateral and not vertical, and therefore this inconvenience, if it should ever arise, would be reduced to a minimum.

An open pit in clay would be dangerous and expensive to manage, if it was sunk to a great depth, but in the Batesville region, a pit could not go to great depths, for the ore-bearing clay is limited in thickness. The thickest deposits are probably not much over a hundred feet, though they may sometimes extend to greater depths in holes in the underlying Izard limestone; but most pits, especially where the ore bed has no thick chert covering, would reach bed rock at from thirty to eighty feet. Most of the manganese ore occurs in a bed of clay situated on or near the summits of limestone hills, the slopes of which are often very steep. In such a position, a large open pit in the clay could be more easily drained than a series of small shafts, and abundant dumping facilities could readily be obtained.

From the above considerations, it seems desirable to conduct mining operations in this region, in places where the chert is thin or only in loose fragments, by means of large open pits or cuts, and in this way eventually to move the whole of the ore-bearing clay bed from the summit of the hill. Two methods might be employed to do this: (1) An open cut might be started into the hill, on its slope at the base of the clay and above the underlying limestone. The ore and the clay could be carried out in carts or on a tramway and dumped on the side of the hill. In this way the whole hill could be stripped of its ore-bearing deposit, and all the ore that is there could be obtained. (2) Large pits could be sunk on the clay bed, and hoisting could be done with a derrick. The derrick should have a long boom so as to reach over as large an area as possible, and could be best worked with a portable engine. When all the ore-bearing clay within reach of the boom had been removed down to the limestone floor, the derrick and boiler could be taken to another position, and this process continued until the whole hill was stripped. The ore and waste material could be dumped on the slopes of the hill where this was feasible, and,

where it was not, they could be carried off on a temporary tramway. Both these methods have their advantages, and the adoption of one or the other must be determined by the conditions surrounding each property.

In cases where there is a heavy capping of chert, it will doubtless be found cheaper to employ the method of shafts and tunnels than of open cuts, as the expense of stripping from fifty to seventy feet of chert is not warranted by the amount of ore beneath. But wherever the chert bed is thin, the ore begins almost from the surface, and in such cases the method of mining in open cuts is undoubtedly preferable.

MINING MACHINERY.

The use of expensive machinery in mining in the Batesville region, with the exception of washers, is not only unnecessary, but is unwarranted by the nature of the deposits. Portable boilers and hoists, and in some cases steam pumps, are all the machinery necessary.

The deposits generally cover isolated hills, and are necessarily limited both in depth and lateral extent. Consequently if mining is to be done on a large scale, numerous localities will be worked out, and no permanent mining plant should be put up in any one place. All equipments should be as light and portable as possible, so that when one deposit is exhausted, they can be cheaply moved to another.

WASHERS.

The only treatment that it is necessary to give the ore in order to prepare it for market, is to free it from the adhering clay. The methods employed for this purpose must vary somewhat with the nature of each deposit. Where the ore is in large masses, it can generally be shipped just as it is mined, as the adhering clay forms an almost imperceptible part of the whole mass; but in some places the manganese contains a great number of small cavities filled with clay, and if this ore is shipped in lump form, the clay greatly lowers its percentage of manganese and often

renders it unmarketable. Such ores should be crushed and cleansed by sizing and jigging. In association with the larger masses of ore, there almost always occur greater or less quantities of small ore, in pieces varying from a sixteenth of an inch to an inch in diameter, known as "wash dirt". It does not pay to collect these by hand and therefore washing is necessary. The form of washer used at the Southern mine has already been described*, and is worked on the principle of sizing and jigging. The washer of John B. Skinner and Company, on Sullivan Creek, differs considerably in its mechanism from that at the Southern mine, but it also is based on the system of sizing and jigging.

In the Cartersville region, of Georgia, the manganese washer commonly used, until the late introduction of a more elaborate process by the Etowah Iron Company, was a simple revolving cylinder, perforated with numerous holes and fed inside by a constant stream of water. The ore is put into the cylinder through a door in one end, revolved until the running water has freed it from all its associated clay, and then removed through the same opening. This is a crude method and looses a large part of the small ore, but it cleanses what remains thoroughly, and has the advantage of being cheap for work on a small scale. There is less small ore in the Georgia region than in the Batesville country, and the loss is therefore less than it would be in the latter place. The amount of loss might be reduced by making the perforations in the cylinder smaller; but there is a limit to this reduction, for if the holes are too small they will clog.

The system of sizing and jigging is undoubtedly the one best suited for the Batesville region, and requires the only expensive plant needed in either the mining or the preparation of the ore. A position suitably situated as regards the source of the ore, the water supply, and transportation should be selected for the washer. The water supply is of prime importance and a washer ought always to be placed where a bountiful flow can be had. The best position is on one of the numerous creeks or large springs of the manganese area. It is not advisable to place it

* Pages 268-269.

on the hill from which the ore is being taken, as it is generally difficult and expensive to get water in such places, and when the hill is worked out the washer is in an inconvenient position for ore from other hills. A central position in the lower country is desirable, and it should be so selected as to be accessible to the greatest number of ore localities and to transportation.

TRANSPORTATION.

The Batesville branch of the St. Louis, Iron Mountain and Southern Railway leaves the main line at Newport and runs northwest, up the north side of the White River, for twenty-nine miles to Batesville. Thence it goes northwest for twelve miles and terminates at Cushman, almost in the center of the manganese region.

None of the workable deposits of manganese are more than twelve miles from Cushman, and most of them are within six miles of that town or of some other point on the railway between there and Batesville. Many of the best localities are not more than two or three miles distant from the railway, and the Southern mine is less than one mile.

The country roads connecting with points on the railway could be made good at a small expense, for the large amount of limestone and loose chert throughout the region, if covered with gravel and kept in proper repair, would make an excellent road bed.

Teams can be hired at from $2.00 to $3.00 per day, but hauling in this region can be done much more cheaply by contract than by day work. Railway freights from Cushman to St Louis are $2.25 per ton; to Chicago from $3.75 to $3.85, according to the part of the city; and from Cushman to Pittsburg, Johnstown, or Allegheny City, about $5.00 per ton. All these places are accessible markets for Batesville manganese, though at present almost all the ore from that region is consumed by the Illinois Steel Company, of Chicago.

In former times, before the railway was built from Newport to Cushman, the ore was hauled to the White River, taken in barges to Newport, and there transshipped to the cars. For

some of the manganese localities in the Lafferty Creek basin, the White River is still more accessible than the railway, and in such cases river transportation to Batesville or Newport might be used, but the expense and loss in reshipping the ore at these places are items to be considered. The ore could also be shipped by barge down the White River to the Mississippi and thence to any point desired, but railway rates are usually so adapted as to compete successfully with such a method of transportation.

FUEL.

The Batesville manganese region is a heavily timbered country, and good hardwood can be had, in large quantities, at from $1.60 to $2.50 per cord. Wood can be cut on private land for $1.25 per cord. No workable coal is found nearer than that of the central Arkansas region, and this could not compete with good cord wood at the above prices.

TOWNS AND SETTLEMENTS.

The largest town in the manganese region is Batesville, and the next most important places are the smaller settlements of Cushman and Barren Fork.

Batesville.—Batesville is situated on the north side of the White River, twenty-nine miles above Newport, and is connected with the latter town by the Batesville branch of the St. Louis, Iron Mountain and Southern Railway. It is one of the oldest towns in the State of Arkansas and was first settled in 1815. It is the county seat of Independence county, has about 3,000 inhabitants, and is one of the largest towns in the northern part of the state. The White River is navigable as far as Batesville at almost all times of the year, and at proper stages of the water steamers can go up the river for over two hundred miles above the town.

Batesville has always been identified with the manganese industry; and, with the facilities of the town for both railway and river transportation, it is an important source of supply, not only for the country immediately to the north, but also for the numerous smaller towns on the upper part of the White River.

Cushman.—The town of Cushman is situated in 14 N., 7 W., the west half of section 9, and occupies a position on the divide between the Polk Bayou and the Lafferty Creek basins. Immediately west of the town, the waters drain into Blowing Cave Creek and thence into East Lafferty. Immediately east of it, the waters drain into Prairie Creek and thence into Polk Bayou.

Cushman is the terminus of the Batesville branch of the St. Louis, Iron Mountain and Southern Railway. It is a village of about a hundred inhabitants and is the shipping point for all the manganese mined within accessible distances. It is also the point from which freight teams start for Barren Fork, La Crosse, Melbourne, Lunenburg, and numerous other towns to the north and west. The region in that direction has no railway, and almost all supplies, with the exception of those that are taken up the White River, have to go through Cushman.

Barren Fork.—Barren Fork, also known as Dry Town, is a settlement of about 200 inhabitants in Izard county, six miles north of Cushman. It lies near the northern limit of the manganese region and is on the mail-route from Cushman to Melbourne. As yet it has no railway.

Other towns in the neighborhood of the manganese region.—Outside of the manganese region, there are numerous other towns. Along the line of the Batesville branch of the St. Louis, Iron Mountain and Southern Railway are the towns of Moorefield, Sulphur Rock, and Newark; while still further east, the town of Newport, situated on White River at the junction of the Batesville branch road with the main line of the St. Louis, Iron Mountain and Southern Railway, is rapidly growing in importance. Its facilities for water and railway transportation have materially favored its growth. The old town of Jacksonport, on the Batesville and Brinkley Railway, is situated on the White River, about four miles above Newport.

Besides the places already mentioned, the villages of Jamestown and Marcella are beautifully situated at the foot of the Boston Mountains, and the old settlement of Elgin is on the Black River about twenty-five miles east of Batesville.

Outside of the towns, the country is fairly well settled by a farming population, and the numerous places marked on the map, but not mentioned above, are post-offices or country stores.

CHAPTER XII.

THE MANGANESE DEPOSITS OF SOUTHWESTERN ARKANSAS.

LOCATION OF THE DEPOSITS.

Geographic position.—Under the heading "southwestern Arkansas" are included the manganese localities found at intervals from Pulaski county on the east, to Montgomery and Polk counties on the west. The name is employed here not only because it is the term by which the region is commonly known throughout the state, but because it is thus distinguished from the "northern Arkansas" or "Batesville manganese region." The area in question lies entirely in the western half of the state, and though it is nearer the central east-west line than to the southern border, it is well within the southwestern quarter of the state.

The manganese area in this region includes a belt of country running from near Little Rock in Pulaski county, in a southwest direction to Hot Spring county, thence west to Montgomery county, and from there a little north of west through Polk county, almost to the boundary of the Choctaw Nation in Indian Territory. This area varies in width from four or five to ten or twelve miles,* and in length it is about a hundred and twenty-five miles. It is not to be inferred that manganese is found everywhere throughout this belt, as the various localities are often separated by many miles of territory in which no ore occurs; but wherever the ore deposits are found, they are similar in character, mode of occurrence, and geologic relations, and are therefore most consistently treated together, as different exposures of the

* This width refers simply to the part of the region in which manganese has been found, and not to the entire width of the novaculite area (see pages 306-307) which is from twenty to twenty-five miles in width.

same, or closely related ore-bearing rocks. The belt includes parts of Pulaski, Saline, Garland, Hot Spring, Pike, Montgomery, and Polk counties.

Topographic position.—The region in which manganese occurs in southwestern Arkansas is a rugged, mountainous area, with its higher elevations reaching from 1,500 to probably over 2,000 feet above the sea, and from 500 to possibly over 1,000 feet above the surrounding drainage. It is the first really mountainous country met going north from the low, flat, pine region of the extreme southern part of the state. On the north it is separated from the valley of the Arkansas River by a parallel range of mountains, rising sometimes several hundred feet higher than those in question, and known in different places by different names, among which are White Oak Mountain, Cedar Mountain, Blue Mountain, Fourche Mountain,* Irons' Fork Mountain, Rich Mountain, and others.

Between these two series of mountains, throughout the larger part of the region, the Ouachita River occupies an east and west valley, varying from two or three to twelve miles or more in width. The river rises in Indian Territory, a short distance west of the northwestern corner of Polk county, and keeps a general easterly course for almost seventy-five miles; though to follow the curves of the river, the distance would be much greater. At the western end of Garland county, it turns southeast, cutting directly across the mountains and forming numerous steep-sided ravines. At the old town of Rockport, where it emerges from the mountains, it changes its course to a general southerly direction, and flows thence south and southeast until it empties into the Black River, a tributary of the Red River, in the state of Louisiana.

From the intimate association of the Ouachita River with the novaculite mountains in which the manganese occurs, the latter have been named the Ouachita Mountains by the State Geologist. Previously, no name had been given to the range as a whole,

* This name does not refer here to Fourche Mountain on the outskirts of Little Rock. It is the same name locally applied to a part of the mountains in Perry county and to a part in Polk and Montgomery counties, both of which areas are immediately south of Fourche la Fave, a tributary of the Arkansas River.

though many local names were employed. Thus in the region of Pulaski county, west of Little Rock, the mountains are locally called the Fletcher Range; near Hot Springs, in Garland county, they are known as the Hot Springs Mountains; in the northern part of Clark and Hot Spring counties they are known as the Trap Mountains; at the head waters of the Little Missouri River, they are known as the Little Missouri Mountains; and around the head waters of the Cossatot River they are known as the Cossatot Mountains. Besides these names of groups of mountains, individual names are given in many places to those elevations which form marked features of the region. This is especially true of the country between the head waters of the Little Missouri and the Cossatot Rivers: here Leader, Hannah, Brushy, Raspberry, Tall Peak, Briar Creek, He, Prairie, McKinley, Porter, Sugar Tree, State House, Little Musgrove, Shadow Rock, Buckeye, and numerous other mountains are well known throughout the region by their individual names.

Speaking in a general way, the Ouachita Mountains consist of a series of parallel ridges, running in a direction varying from east-west to northeast-southwest, and to northwest-southeast; but characterized, on the whole, by a general east-west trend. Sometimes eight or ten of these ridges are crossed in a distance of as many miles, and at other times the whole range is represented by less than half that number scattered over a breadth of twice the distance. Whatever the local strike in a given area may be, all the ridges of that area follow a general parallel direction, often curving around and joining each other at their extremities, and thus forming a zigzag across the country in a manner directly dependent on the disturbances to which the region has been exposed. The ridges are separated by mountain streams, and frequently rise abruptly to a sharp serrated crest only a few feet wide. Viewed from a distance, they form long, narrow elevations with undulating summits, rising in isolated peaks, or sloping off into low places, through which mountain trails find passages across the country. Sometimes the ridges run continuously for many miles without any considerable break, but

occasionally a stream has cut its way through and forms a steep, rocky gorge, as it intersects successively each ridge in its course.

PREVIOUS GEOLOGIC INVESTIGATIONS OF THE MANGANESE DEPOSITS.

Before the explorations of the present Survey, very little geologic work had been done on the manganese deposits of southwestern Arkansas. Dr. David Dale Owen in his report of 1859–60* gave a description of the region, but did not mention the existence of the manganese ores.†

In 1888, Dr. T. B. Comstock‡ described a number of manganese localities in the region in question, and gave numerous analyses. His work on this subject, however, was subordinate to his investigation of the gold and silver question, and therefore was not carried out in detail. References to his descriptions of different localities will be made later on, in the detailed discussion of the region.

The annual reports of the Mineral Resources of the United States, from 1886 to 1888, published by the United States Geological Survey, contain short notices by Mr. Joseph D. Weeks of the manganese ores of southwestern Arkansas, and several analyses are given.

The issue of the Age of Steel, of St. Louis, Missouri, for September 3, 1887, contains an article on the manganese deposits of Polk county, together with analyses and a general description of the region.

With the exception of the above mentioned publications, and of occasional newspaper articles and reports of mining companies, no further information on the deposits in question has as yet appeared.

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* Second Report of a Geological Reconnoissance of the Middle and Southern Counties of Arkansas, 1859 and 1860.

† Dr. Owen gave an analysis of manganese ore in this report, but the specimen was from the Batesville region in the northern part of the state. He also gave analyses showing the existence of manganese in the soils of various counties in Arkansas. His investigations in the Batesville region, published in his report of 1858, have already been described on pages 100-103, and 145-154 of the present report.

‡ Geological Survey of Arkansas, Vol. I., 1888, J. C. Branner, State Geologist.

HISTORY OF MANGANESE MINING IN SOUTHWESTERN ARKANSAS.

Manganese mining in southwestern Arkansas has been carried on to only a limited extent, probably not more than thirty tons of ore having been shipped from the whole region. A great many places have been prospected, but the only considerable amount of work that has been done is on the land of the Arkansas Development Company, in Polk county, on the Brushy Creek branch of the Cossatot River. This company worked during the year 1888 and continued until April, 1889, when operations were suspended. A shaft was sunk to a depth of a hundred and forty-two feet, and a tunnel about five hundred feet long was run in the side of a mountain. Many prospect openings were also made in the surrounding country, from the head waters of the Cossatot to those of the Saline River. About twenty tons of ore are said to have been taken out of the shaft on Brushy Creek, and this represented practically all the manganese that was mined by this company.

About the same time, the Capitol Land and Mining Company carried on operations in Pulaski county, twelve miles west of Little Rock, in what is called the Fletcher Range. A few small prospect pits and tunnels were made, but no ore was shipped, and work has been discontinued.

The only shipments of manganese ore known to have been made from the whole region, were a few tons of the ore mined by the Arkansas Development Company and four tons from a small pit on the Burns Claim, on North Mountain, near the head waters of the Little Missouri River. A sample of five hundred pounds was also shipped by Mr. Webb Thornton, from his claim on Leader Mountain, some five miles south of North Mountain.

Besides the above mentioned localities, many small prospect pits have been made throughout the mountains wherever manganese crops out, but no ore has been shipped from them. Most of them have been made by the Arkansas Development Company and by Mr. Burns.

MINING POSSIBILITIES.

Cause of failures. — Manganese mining in southwestern Arkansas has not yet been carried on successfully. The reason for this lack of success is commonly supposed to be the distance of the deposits from railway transportation. The manganese area of Pulaski county is from seven to twelve miles from the line of the St. Louis, Iron Mountain and Southern Railway, while that of Montgomery and Polk counties is from forty to sixty miles from the railway. This lack of transportation facilities may in some cases have prevented further attempts than have been made to mine the ore, but, even if there were better facilities, the peculiar mode of occurrence of the ore would always prevent the development of the deposits on a commercially important scale.

The aggregate amount of manganese in the region is undoubtedly large, but it is distributed over an extensive area, and in almost all places it is hopelessly scattered through the rock in small nests and seams. If these nests and seams were in sufficient quantities the rock might be crushed and the ore concentrated by washing, but the pockets containing them are too small to permit the expense of machinery. It is a popular idea that the ore will increase in quantity at a depth, but there is absolutely no reason to expect this, as such deposits are just as likely, and sometimes even more likely, to become poorer at a depth than they are to improve.

From the nature of the deposit it is to be expected that the ore at a depth is, at the very best, no more plentiful than in the surface outcrops of the so-called "lodes"; that is, that it exists as a series of pockets separated by greater or less distances of barren rock. With very few exceptions the pockets of ore seen on the surface can not be worked at a profit, and in the rare cases where a small profit might be made, the amount would not be enough to pay for sinking through the barren rock that separates the pockets from each other. The intervening thickness of barren rock is much greater than the depth of any one pocket; and, moreover, it is possible that the ore in the deeper pockets has undergone a lesser degree of segregation than the ore near the

surface, and that it may, therefore, be in even a still less available form than the latter.

Areas operated.—Two areas in the region in question have been the seats of considerable excitement over the manganese deposits: one is in the Fletcher Range, in western Pulaski county; the other is in the region of the head waters of the Little Missouri and Cossatot Rivers, in Montgomery and Polk counties. In Pulaski county the deposits are not such as to warrant the expenditure of any capital whatever in exploring them. The ore occurs both in place in the rock, and as a bog ore in the McHenry Creek bottoms. The amount of ore in the rock is insignificant, while the bog ore, though sometimes in considerable quantities, is mostly of too poor grade to be of any value. It generally contains considerable quantities of iron and in most cases blends into a very impure bog iron ore, as shown by the analyses on page 330. Small areas of fairly good ore can be found in the poorer bog ore, and specimens can be collected which contain over 50 per cent of manganese, but the quantity of such ore available for commercial purposes is too small to be mined.* It is clear, therefore, that no manganese mining can be profitably carried on in Pulaski county.

In the region of Montgomery and Polk counties some of the surface exposures of manganese ores are not so small as those in Pulaski county, and in a few cases the deposits could be worked at idle times by people living in the country, and fair returns could be obtained. The pockets could not be followed down to any considerable depth, however, as they would soon be exhausted; and the industry would not warrant the investment of capital. The value of the small quantities of ore that might be mined in Montgomery and Polk counties, would be in the considerable percentage of peroxide of manganese, or pyrolusite, that many of them contain. Such ores, when pure, are valuable for use in the manufacture of chlorine and for other chemical purposes; while those ores which are also free from iron are valuable in the manufacture of glass. For these uses many of the southwestern Arkansas ores would bring from forty to

* For further details about this deposit see pp. 328.

eighty dollars per ton, and the best grades would bring even more. This value is much greater than that paid for ore for the manufacture of spiegeleisen or ferro-manganese, which brings from ten to twenty dollars per ton, according to the quality; moreover, the ores of Montgomery and Polk counties are generally, though not always, too high in phosphorus, so far as the analyses at hand show, to be desirable as a source of spiegeleisen and ferro-manganese.

In the country between the manganese area of Pulaski county and that of Montgomery and Polk counties, that is, in Saline, Garland, Hot Spring, and Pike counties, manganese is occasionally found, but it is in insignificant quantities. The iron ore which frequently occurs in this area is often mistaken by prospectors for manganese and many claims have been taken up under this delusion.

It becomes evident, therefore, that in southwestern Arkansas, that is, in the region from Pulaski county on the east to Montgomery and Polk counties on the west, no extensive manganese mining can be carried on at a profit. There are no large bodies of ore anywhere on the surface, and the nature of the deposit is such as to make it utterly useless to attempt to search for more extensive bodies at a depth.

THE GEOLOGIC RELATIONS OF THE MANGANESE DEPOSITS.*

The manganese deposits of southwestern Arkansas represent an interbedded stratum in the upper part of the gray novaculite of that region. The novaculite rock is overlain and underlain by a series of shales, quartzites, and sandstones, which are destitute, so far as known, of any commercially important deposits of manganese ore. As regards the geologic age of the ore-bearing rocks, all that can at present be said is that they are probably of Lower Silurian age. The only fossils that have been found are

* The geology and structural features of the Ouachita Mountains, in which the manganese deposits are situated, have been worked out by Mr. L. S. Griswold, of the Survey, in his investigation of the novaculite series, and will be described by him in Vol. III of the reports of the Geological Survey for 1890. The subject will therefore be mentioned here only in a general way, and to such an extent as is necessary for the proper comprehension of the occurrence of the manganese ores. For further details the reader is referred to the above mentioned report.

a few graptolites discovered by Mr. L. S. Griswold, of the Survey, in the shales associated with the novaculites. These have been determined by Professor Henry S. Williams and by Dr. R. R. Gurley as belonging mostly to the Trenton horizon of the Lower Silurian; but certain specimens from one locality were determined by Dr. Gurley as Calciferous forms. As the exact stratigraphic relations of some of the graptolite shales to the novaculite are as yet uncertain, no more definite correlation can at present be made.*

To the north of the Ouachita Mountains are a series of sandstones, quartzites, and shales, comprising the mountains on the divide between the waters of the Ouachita and the Arkansas Rivers. These rocks are regarded by the State Geologist as being of Lower Carboniferous age, and are bordered on the north by the Coal Measures of the Arkansas valley.

In their eastern part the Ouachita Mountains come into direct contact with the horizontal Tertiary beds of that section. In their western part they are bounded on the south by a much less rugged, but equally disturbed area of Paleozoic (probably Lower Carboniferous) sandstones and shales, which extend thence south for about twenty miles, until they come in contact with, and disappear under the horizontal Cretaceous and Tertiary strata. The relation of the sandstones and shales south of the Ouachita Mountains to those to the north, has not yet been thoroughly worked out, but it seems probable, as has been suggested by the State Geologist, that they may represent the same horizon and may form the two sides of a wide anticline, each comprising numerous subordinate folds; and that the Ouachita Mountains represent older rocks, and occupy a position in the breach of this great anticline.

THE ROCKS OF THE MANGANESE DEPOSITS.

Nature of the rocks.—The novaculite with which the manganese ores are associated is a siliceous deposit reaching a maximum thickness of probably four hundred and fifty feet, and made

* For the relation of the manganese dep sits of the Batesville region to those of southwestern Arkansas, see pages 99-100.

up of strata differing considerably in physical character. It is composed of almost pure anhydrous silica and varies from a translucent, hard rock of a white, gray, or buff color, having a conchoidal fracture and porcelain-like appearance, to a soft, porous or granular material, of a massive structure and of an irregular fracture. The top of the bed is occupied by the manganese- and iron-bearing stratum, which contains the ores in various forms, from a mere stain to a network of thin pockets and seams. The part of the bed thus impregnated varies from four or five feet to fifty feet in thickness, and in some rare cases probably more.

Immediately underlying the ore-bearing stratum is the "Ouachita stone" stratum, the source of the best of the celebrated Arkansas whetstones. This is fully described by Mr. Griswold, and it is sufficient to say here that it is softer than the rest of the novaculite bed and has a fine grained, porous structure. It often disappears altogether, and even where it is present its outcrop is usually obscured on account of its softness, It is underlain by a much harder novaculite, passing below into a bed of a shaly structure, from forty to a hundred feet in thickness. From this point to the base of the formation the rock is massive and hard, and frequently contains exceptionally hard strata which, on account of their greater resistance to weathering, often form the most prominent feature on the summits of the ridges. This part of the series varies from less than a hundred to over two hundred feet in thickness.

The ore-bearing stratum frequently partakes more or less of the soft nature of the "Ouachita stone", and is sometimes even softer, being easily crumbled in the fingers. From this state there are all stages of hardness, until, in many places, the rock assumes a flinty, porcelain-like structure similar to that seen in the lower part of the formation.

Quartz veins from the fraction of an inch to several inches in thickness are numerous in the novaculite, and sometimes a network of thin quartz veins runs in all directions through the rock. In places, the novaculite itself has been converted to a semi-crystalline quartz rock, and contains small cavities lined

with crystals of the same material. The novaculite is much jointed, the joints running at right angles to the bedding as well as at various other angles to it, though they are generally steeply inclined.

Though the novaculite is, in some cases, probably over four hundred feet in thickness, yet elsewhere it has less than half this thickness, and in some cases it possibly thins out altogether, reappearing beyond. As already stated, the novaculite forms the most prominent feature of the ridges that characterize the region. These sometimes thin out and gradually slope off to the level of the surrounding country in a manner that could, probably, be best explained by supposing a gradual thinning or local disappearance of the novaculite.

Immediately overlying the novaculite, and exposed on the slopes of the ridges, is a series of gray and black siliceous shales* interbedded with more massive strata somewhat resembling in nature the underlying novaculite, but always showing on closer examination a more or less shaly structure, and breaking in large flat slabs. The rock is frequently pierced by a network of thin quartz veins and also contains alternating lenticular strata of brown hematite. Frequently the siliceous shales have undergone a partial decomposition and have been converted into a fine siliceous powder. This is, however, only local, and there frequently occur strata of partly disintegrated rock, carrying fragments of the as yet undecomposed parts and interbedded with unaltered strata. The disintegration is especially marked near the contact of the shales with the ore-bearing part of the novaculite, and also near the hematite deposits in the shales themselves. Good measurements of the thickness of the siliceous shales can rarely be made on account of the highly disturbed condition of the rocks, but they probably aggregate, in their maximum development, about three hundred feet, though they are often much thinner.

Overlying the shales are a series of gray and brown sandstones; and above these is a great thickness of shales varying

* These shales are included by Mr. Griswold in his novaculite series.

from gray and black to yellow and brown. These rocks, though sometime seen in the synclinal troughs of the novaculite, have no connection with the occurrence of the ores of the region, and the reader is referred to the report already mentioned for further details.

Below the novaculite bed there is a series of yellow, brown, or gray shales, underlain by a series of black and gray shales with sandstone strata and sandy limestones. In the shales of the latter series are found the Silurian graptolites already mentioned.

Disturbance of the rocks.—The Ouachita Mountains, considered as a whole, represent a portion of the southern part of an area of great disturbance, which extends from the valley of the Arkansas River on the north, in a southerly direction until it disappears beneath the undisturbed Cretaceous and Tertiary strata of the southern part of the state.

The detailed structure of the mountains themselves is complicated, but in a general way they represent a series of parallel folds, which have given rise to the general east and west ridges already described. Subsequent erosion, however, has greatly altered the character of the surface features originally given by these disturbances, and the novaculite, being more resistant than the associated strata, has controlled the topography. The rocks were originally tilted at high angles, in many cases vertically, and were sometimes overthrown. Erosion has since attacked them, carried away the more easily disintegrated beds, and exposed the upturned edges of the novaculite on the crests of all the higher ridges, leaving that rock as the most conspicuous and characteristic feature of the country. The result is a series of novaculite ridges bordered on their lower slopes by the associated shale and sandstone strata. Such ridges generally exist in the forms of anticlines and monoclines. The summits of the anticlines are often removed for considerable distances; the folds are also often overturned and show a dip in one direction throughout. In the latter case the normal anticlinal dips are

sometimes seen at the base of the ridges in the deeper river and creek passes.

The outcrop of the ore-bearing stratum appears in the novaculite at or near its contact with the overlying siliceous shales, and is generally exposed on the slopes of the ridges as a consequence of the erosion of the latter rocks. It can be traced in this position across the country, following the course regulated by the structure of each ridge. In some places it is represented by bodies of ore, in others by simply a stain in the rocks.

THE MANGANESE ORES.

Mineralogical forms.—The manganese ores of southwestern Arkansas represent oxides of manganese in their different mineralogical forms. The minerals psilomelane and pyrolusite have been identified beyond a doubt, and they probably comprise the larger part of the ores found in this region. They frequently occur in intimate association with each other, the pyrolusite often coating masses of psilomelane or encrusting the interiors of cavities lined with that ore. Probably some of the samples of manganese ores collected in this region contain manganite and possibly braunite, but these minerals have not yet been positively identified. A material representing a mixture of clay and rock fragments, more or less impregnated with oxide of manganese, and locally known as "bog ore," is found in the banks of McHenry Creek, in Pulaski county.

Below are given descriptions and analyses of typical specimens of psilomelane and pyrolusite found in this region.

Psilomelane.—Specimen from the head waters of the Little Missouri River, in the southwestern part of Montgomery county. This is a black or steel-blue mineral; opaque; lustre submetallic; powder dark brown; fracture conchoidal, highly developed, with a bright glossy surface; hardness 7. Its specific gravity as determined by the chemist of the Survey is 3.95. It frequently occurs in reniform or botryoidal masses with smooth black surfaces.

With fluxes it gives reactions for manganese; it dissolves in hydrochloric acid with the evolution of chlorine and leaves a slight residue.

An analysis made by R. N. Brackett of this mineral dried at 110°–115° Centigrade, gave the following results:

Analysis of psilomelane from southwestern Arkansas.

Manganese protoxide (MnO)	73.17
Oxygen (O)	15.11
Ferric oxide (Fe_2O_3)	0.26
Alumina (Al_2O_3)	6.52
Cobalt oxide (CoO)	trace
Lime (CaO)	1.58
Baryta (BaO)	0.05
Potash (K_2O)	2.12
Soda (Na_2O)	2.35
Phosphoric acid (P_2O_5)	trace
Silica (SiO_2)	0.15
	101.31

The analysis and the physical features of the mineral correspond in most respects to psilomelane. Rammelsberg* classifies different varities of psilomelane under two headings: those high in baryta and low in potash are grouped as baryta-psilomelane; those low in baryta and high in potash are grouped as potash-psilomelane. The mineral in question cannot be classed as a baryta-psilomelane, as its percentage of that ingredient (0.05) is insignificant, while true baryta-psilomelane generally contains several per cent of baryta and sometimes as much as 16 or 17 per cent. On the other hand potash-psilomelane, though it sometimes contains over 5 per cent of potash, does not usually show the high percentage of soda (2.35) found in the above analysis. Of all the analyses quoted by either Dana or Rammelsberg, the one showing the highest per cent of soda was made by Schmid† of a sample from Oehrenstock, Germany, which contained 0.25 per cent of that ingredient. In the case of the Arkansas sample, therefore, the soda is extraordinarily high, but it seems probable that this ingredient simply replaces a part of the potash; and, in the absence of any class of soda-psilomelane, as well as in the consideration of the noticeable amount of potash

* Handbuch der Mineralchemie, second edition, 1875, p. 190.

† Pogg. Ann., Vol. CXXVI., p. 151.

besides the soda in the mineral, the latter may be provisionally classed as a potash-psilomelane.

Pyrolusite—Specimen from Cossatot Mountain, in the southeastern part of Polk county. This is a black, opaque mineral; lustre submetallic; streak black; hardness 2. It is in the form of a fibrous crystalline aggregate, the fibres varying from a sixteenth to an eighth of an inch in length, and often arranged radially around a spherical mass of the same mineral in a more minutely crystalline form.

An analysis made by R. N. Brackett of this mineral dried at 110°–115° Centigrade, gave the following results:

Analysis of pyrolusite from southwestern Arkansas.

Manganese protoxide (MnO)	76.90
Oxygen (O)	16.66
Ferric oxide (Fe_2O_3)	1.06
Alumina (Al_2O_3)	0.79
Cobalt oxide (CoO)	strong trace
Lime (CaO)	0.52
Baryta (BaO)	2.83
Magnesia (MgO)	0.14
Potash (K_2O)	0.26
Soda (Na_2O)	0.20
Silica (SiO_2) and insoluble matter	0.52
	99.88

The molecular ratio of MnO : O in the above analysis is 1.08 : 1.04, which closely approaches the theoretical ratio 1 : 1 of pyrolusite (MnO_2).

It is a noticeable feature of this specimen that the percentage of baryta (2.83) is much larger than is usual in pyrolusite, which generally contains less than 1 per cent of that ingredient.

Iron ores.—The iron ores which occur either with or without manganese in the gray novaculite, and those which occur in the siliceous shales overlying the novaculite, are in the forms of more or less hydrous sesquioxides. The more common forms are:

(1) Brown limonitic ore, hard and often highly siliceous. This variety generally occurs in the siliceous shale that overlies

the novaculite, though it is also found at the junction of the two rocks. It forms irregularly interbedded lenticular strata and is more plentiful than any of the other varieties.

(2) A dark brown, hydrous sesquioxide of iron; porous, honeycombed structure, glittering vitreous to resinous lustre throughout; streak chrome yellow; hardness 4 to 5. It frequently occurs in a mass composed of stalactitic and botryoidal forms, and the cavities between these give it its porous structure. Its cavities and cracks are frequently lined with a brilliant red ochre. Its most characteristic feature is its lustre, which is sometimes almost glassy or of a pitch-like character. This distinguishes it from all the other ores of the region. It is found only in the gray novaculite.

The following analysis made by W. A. Noyes of a specimen of this mineral from the Bud Jones claim, 3 S., 24 W., section 29, the north half, shows its composition:

Ferric oxide (Fe_2O_3)	77.91
Manganese peroxide (MnO_2)	none
Manganese protoxide (MnO)	0.39
Alumina (Al_2O_3)	0.50
Water (H_2O)	16.04
Phosphoric acid (P_2O_5)	4.10
Silica (SiO_2)	0.84
	99.78
Metallic iron	54.54
Metallic manganese	0 30
Phosphorus	1.79

The hydration of this mineral is almost exactly intermediate between that of true limonite ($2Fe_2O_3$, $3H_2O$) which contains theoretically 14.4 per cent water, and xanthosiderite (Fe_2O_3, $2H_2O$) which contains 18.4 per cent of water. The water of the mineral in question approaches a little nearer that of limonite than of xanthosiderite, but the difference is insignificant; while the pitch-like lustre suggests a resemblance to some forms of the latter.

(3) A black, glossy, hydrous sesquioxide frequently in reniform and botryoidal masses; streak brown; hardness 3. The

surfaces of the masses often have a brilliantly iridescent gloss, showing a variety of shades of blue, green, pink, and other colors. This ore occurs in the gray novaculite, generally with the manganese, though sometimes free from it. The water in it generally approaches that of limonite.

(4.) A mineral somewhat resembling the last in general appearance, but with a submetallic lustre; reddish-brown streak; hardness 4.5. A specimen of this mineral examined by R. N. Brackett, contained only 5.4 per cent of that ingredient, and has been determined by him as turgite ($2Fe_2O_3$, H_2O), which contains theoretically 5.3 per cent of water.

(5) A black, massive mineral; compact structure; lustre submetallic; streak reddish-brown; hardness 5. It frequently shows the same iridescent surface as the last variety.

The following analysis made by W. A. Noyes of a sample of this mineral from the Bud Jones claim, 3 S., 23 W., section 22, the southeast quarter of the northeast quarter, shows its composition:

Ferric oxide (Fe_2O_3)	88.56
Manganese peroxide (MnO_2)	none
Manganese protoxide (MnO)	0.05
Alumina (Al_2O_3)	1.40
Water (H_2O)	8.05
Phosphoric acid (P_2O_5)	0.45
Silica (SiO_2)	1.53
	100.04
Metallic iron	54.54
Metallic manganese	0.04
Phosphorus	0.20

The hydration of the mineral is intermediate between that of turgite ($2Fe_2O_3$, H_2O) which contains theoretically 5.3 per cent of water, and that of goethite (Fe_2O_3, H_2O) which contains theoretically 10.1 per cent, but it approaches nearer the latter. Its features, however, are such as to suggest the possibility of its being a hematite partially altered by hydration on its surface exposure.

COMMERCIAL VALUE OF THE MANGANESE ORES.

The treatment of the commercial value of the manganese ores properly belongs here, but that value in this case is so dependent on the mode of occurrence of the ores that the subject has already been taken up under the discussion of the mining possibilities of the manganese deposits on pages 306-308.

The following analyses represent the composition of manganese and manganiferous iron ores from the land of the Arkansas Development Company, and have been kindly furnished the Survey by Mr. W. E. Barns, Editor of the Age of Steel, St. Louis, Mo.

Analyses of manganese and manganiferous iron ores from southwestern Arkansas.

No.	Manganese.	Iron.	Silica.	Phosphorus	Analyzed by.
1	60.28	.....	.....	0.413	Regis Chauvenet & Brother.....
2	58.36	.....	9.02	.....	St. Louis Sampling and Testing Works.
3	55.80	0.50	3.72	0.038	" " " " "
4	51.54	.....	.....	0.167	Regis Chauvenet & Brother.....
5	48.65	2.03	11.86	0.308	St. Louis Sampling and Testing Works.
6	48.34	.....	.....	0.449	Regis Chauvenet & Brother.....
7	40.51	25.53	0.80	0.767	St. Louis Sampling and Testing Works.
8	27.68	35.39	1.88	0.230	" " " " "
9	26.20	16.83	29.00	0 343	" " " " "
10	22.84	.....	0.42	0.047	" " " " "
11	11.93	22 26	44.40	0.576	" " " " "
12	2.06	50.38	.....	1.450	Regis Chauvenet & Brother..... .....

The following table of the analyses made by the Survey shows the composition of manganese ores from different parts of southwestern Arkansas, including Pulaski, Hot Spring, Pike, Montgomery, and Polk counties. All the samples analyzed were collected by the Survey. Analyses 1, 9, and 13 were made of picked specimens, and represent a better grade of ore than the average of the deposits from which they were taken. The

Analyses of manganese ores from southwestern Arkansas.

No.	LOCALITY.	OWNER.	Manganese.	Iron.	Silica.	Phosphorus	Moisture.	Manganese peroxide.
1	Pulaski county, 1 N., 14 W., section 24, NW	Capitol Land and Mining Company.	59.68	3.09	4.83	0.001		14.13
2	" " 1 N., 14 W., section 24, SE., NW	" " " " "	27.34	2.88	42.83	0.116	1.42	
3	" " " " " " " " " "	" " " " "	8.08	11.82	63.19	0.270	3.67	
4	" " 1 N., 13 W., section 33, NW., NW	R. W. Worthen	40.39	2.17	29.30	0.003		
5	" " " " " " " " " "	" " "	13.31	0.87	74.79	0.015		
6	Hot Spring county, 4 S., 20 W., section 26, NW., SE	Conley Sullivan	41.54	14.15	1.29	0.560		60.58
7	Pike county, Line Mountain, 5 S., 26 W		30.93	9.21	5.86	0.320		42.09
8	Montgomery co., Fancy Hill Mountain 4 S., 26 W., sec. 28		48.02	5.55	0.52	0.310		71.78
9	" " North Mountain, 4 S., 27 W	Burns claim	56.66	0.13	0.15	trace		82.10
10	Polk co., McKinley Mountain, 4 S., 28 W., section 12		49.24	2 04	2.98	0.380		71.41
11	" " Tall Peak Mountain, 4 S, 29 W., section 24	Arkansas Development Company	52.16	4.00	0.24	0 390		77.60
12	" " Manganese Mountain, 4 S., 29 W		42.75	2.72	10.46	0.450		62.75
13	" " Cossatot Mountain, 3 S., 29 W		59.55	0.74	0.52	none		90.52

rest of the samples were so selected as to represent as nearly as possible the average of the deposit. Analyses 1 to 3 represent the so-called bog ore of McHenry Creek. Additional analyses of the bog iron ore from the same locality and a description of the deposit are given later in this chapter, in the discussion of the property of the Capitol Land and Mining Company in Pulaski county.

MODE OF OCCURRENCE OF THE MANGANESE ORES.

The manganese ores occur as nests, pockets, and short discontinuous seams, from a small fraction of an inch to a foot or more in thickness. The latter thickness, however, is rare, and three or four inches usually represents the maximum thickness of any one mass. Such bodies of ore occur scattered in varying quantities and in a great many different ways through a hard or soft novaculite rock: they either occupy planes of bedding and joint cracks; or occur as segregations in the rock; or form the cement of a brecciated novaculite, in which the masses of rock vary from a fraction of an inch to several feet in diameter, and are surrounded on all sides by layers of manganese ore from a fraction of an inch to several inches in thickness. The part of the rock thus impregnated varies from two or three feet to fifty feet and sometimes more in width. The ore, however, forms only a small proportion of the mass, in some places not more than 1 per cent, while in others, especially where the ore-bearing stratum is thin, it forms a much larger percentage.

The iron ores in some places are intimately mixed with the manganese in the form of ferruginous manganese ores or manganiferous iron ores; in others the two ores occur in the same pocket but in separate masses; and in still others they occur in different places along the same ore-bearing stratum. On He Mountain, described in the next chapter, there are geodes of brown hematite lined on the inside with black manganese ore; and a frequent occurrence elsewhere is a kernel of brown hematite coated with manganese, either as a hard incrustation of massive ore, or as

radiating fibrous crystals of pyrolusite. Stalactitic ore with hematite inside and manganese outside sometimes occurs.

The iron ore usually shows a tendency to follow lines of bedding, but sometimes, in both the novaculite and the shale, it occurs in joints or fault lines, forming deposits as much as two or three feet in thickness. These seem to have been formed by the collection of the ore in such positions from originally bedded deposits. Such a case is described later in this chapter on the Bud Jones claim, 3 S., 23 W., section 29, in Montgomery county.

The rock carrying the manganese represents an interbedded stratum in the upper part of the gray novaculite, usually occurring at or near the contact of that bed with the overlying gray and black siliceous shale. Similar ores probably sometimes occur in small quantities in the lower part of the novaculite, but they are of no importance. The ore-bearing stratum generally dips steeply, often almost vertically, and its outcrop is often traceable for many miles, following along the upper slopes or even the summits of the ridges, at or near the contact of the two rocks. It is only locally, however, that ore occurs in it in any appreciable quantities. Its course is almost always marked by a greater or less stain of iron or of manganese or of both, and at irregular intervals this stain increases in quantity until it forms the deposits just described. Sometimes the latter are within a few yards of each other, but usually they are several hundred yards apart and often several miles, separated by practically barren rock.*

As has already been stated, the whole region has been thrown into a series of parallel folds, striking from east and west to various angles to that direction. The novaculite forms the predominating rock in these ridges, and wherever it is exposed, more or less signs of the ore-bearing stratum

* The deposits of mixed manganese and iron ores, and even many that are all iron ore, are frequently supposed by prospectors to be all manganese. This gives a very erroneous impression of the quantity of manganese present, as the iron occurs in considerably the larger quantity. Manganese frequently does comprise the whole of the deposit, but just as often it is mixed with iron, or blends altogether into that ore.

occur; so that in a region where there is a series of parallel ridges, there is a series of exposures of the stratum running parallel to these ridges. Such exposures are locally, but as will be explained on page 325, erroneously called "lodes," and are especially well seen in the region between the head waters of the Little Missouri and the Cossatot Rivers, in the southwestern part of Montgomery county and the southeastern corner of Polk county. Here there are often eight or ten parallel ridges, all showing the ore-bearing stratum. The latter, to be sure, may be represented simply by a stain for the whole length of the ridge, but perhaps on the next ridge the exposures of the same stratum contain pockets of ore.

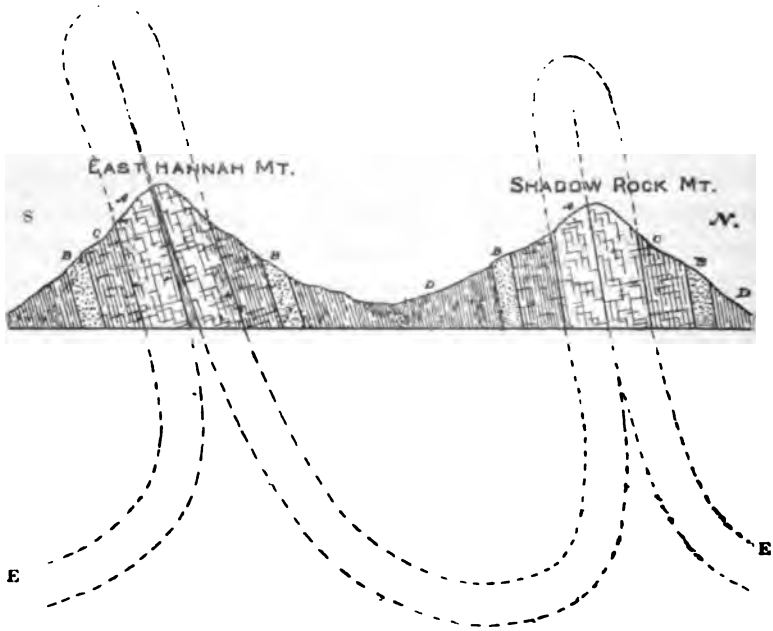

Figure 24. *North-south section through East Hannah and Shadow Rock Mountains, Polk county, showing the folding of the manganese-bearing stratum.*

A. Gray novaculite.
B. Sandstone.
C. Siliceous shale.
D. Shale and sandstone.
E. Extension of the ore-bearing stratum.
Horizontal scale: 1 inch=½ mile; Vertical scale: 1 inch=1,000 feet.

The accompanying figure represents a section across East Hannah and Shadow Rock Mountains, a mile east of the

Cossatot River, and illustrates the cause of the repeated exposures of the same ore-bearing stratum on the slopes of parallel ridges. East Hannah and Shadow Rock are two of the main ridges in Polk county, and run in a general east-west direction across the region of the head waters of the Cossatot. The dotted lines on the summits of the mountains indicate the direction of the continuation of the gray novaculite before it was eroded to its present level. They are not intended, however, to represent the absolute distance of this continuation, as that may be either greater or less than represented in the figure. The dotted lines below the surface are intended to represent the probable direction of the underground extension of the gray novaculite; but, just as with the lines on the summits, they are not intended to represent the absolute depth of this extension. The outside one (marked E in the section) of the two lines represents the contact of the gray novaculite and the siliceous shale, and the position of the ore-bearing stratum is approximately on this line. The extension of the line, therefore, below and above the surface represents the extension of the manganese stratum, just as explained with the gray novaculite.

Both ridges are in the form of anticlines overthrown in their upper parts, and it will be seen that the manganese stratum is exposed on both slopes of each mountain. It is rarely, if ever, however, that each exposure of the stratum on any one north and south section contains appreciable quantities of ore, but its position is almost always marked by more or less stain of iron or manganese or of both. Thus on the line of the section represented in the figure, the stratum contains ore on the south side of both East Hannah and Shadow Rock, while a stain is all that represents it on the north side.

The ore-bearing stratum and the rest of the rocks once lay horizontally, and have been brought into their present position by a profound disturbance in the earth's crust. When in its original position, the ore stratum consisted of isolated flat layers of ore-bearing rock separated laterally by

barren areas of the same rock. When it was brought into its present position, the appearance or non-appearance of ore depended on whether the part of the stratum represented in a given exposure on the ridge, was a part that had originally contained one of the flat layers, or whether it was a part of the barren rock that separated these layers. This accounts for the appearance of ore sometimes on both sides of a ridge, sometimes only on one side, and its frequent absence altogether. The original flat layers, however, were connected by a stain of ore in the rock, and hence the existence of a stain now in the exposures where ore is absent from the stratum.

The figure represents only two of many parallel ridges in southeastern Polk county, on all of which the series of phenomena already described occur, but it serves to illustrate the subject in question. Where the ridge is an anticline the ore-bearing stratum is seen on both slopes, at the contact of the novaculite with the overlying siliceous shale. Where it is in the form of a monocline the stratum is seen only on one side.

On the slopes of the ridges there are often strata of brown hematite imbedded in the siliceous shale, striking in the same direction as the manganese-bearing stratum, but always at a lower level. These form lenticular beds from a few inches to four or five feet and more in thickness. Sometimes several of them run parallel to each other at a distance of from a few inches to several feet, separated by similar strata of siliceous shale. The latter have frequently been much decomposed and are in the form of a fine powder containing harder masses of the as yet undecayed parts. This decay, however, is only local, and frequently a decomposed stratum several inches in thickness is bordered on both sides by unaltered beds of the same rock. The iron ore blends into the country rock along the same stratum, and the continuance of any one lead of ore is very uncertain. When it thins out, however, it generally appears again in the same relative position at a greater or less distance

beyond, and the intermediate barren rock is usually stained with iron in the direction of the strike of the deposit.

CHEMICAL ACTION IN THE MANGANESE DEPOSITS.

The deposition of the manganese ores in the novaculite is a subject intimately related to the origin of the novaculite itself, and the transformation of the ores into their present forms, subsequently to their deposition, doubtless has a close connection with the agencies that converted the novaculite into its present form.

It seems probable that the novaculite was originally laid down as a siliceous sediment, subsequently indurated into a compact rock, and still later altered into its present form of anhydrous silica. There is every reason to suppose that the manganese and iron were deposited at the same time as the upper part of the novaculite and just before the deposition of the overlying shale.* The ore frequently, or even generally, occurs as small seams cutting across the stratification, but these seams are discontinuous and represent simply oblong pockets. They rapidly thin out and are probably due to a chemical action in the ore-bearing stratum after the ore was deposited. The stratum considered as a whole, including the seams of ore and the enclosing rock, follows certain stratigraphic positions through all the many contortions to which the rocks of the region have been subjected. If all the outcrops of the deposit on the many ridges were added together, they would make a length of several thousand miles, and yet not once in this distance has the ore-bearing stratum, *as a whole*, been observed to cut across the strike of the rocks.

The ores were probably laid down during the deposition of the enclosing rock in the forms of oxides or carbonate; and later, either during the formation of the deposit or subsequently, any carbonate that may have existed was converted

* The term "lode" as applied to the manganese and iron stratum is wrongly used: according to F. Prime's translation of Von Cotta's Treatise on Ore Deposits, page 26, lodes are "aggregations of mineral matter containing ores in fissures."

to the oxide form. Still later, chemical action has altered both the chemical character of the oxides and their position in the ore-bearing stratum. Thin layers of ore in planes of bedding are often cut by joints, and these joints are sometimes empty and sometimes filled with ore. Where they are filled, the ore in them cuts directly across the ore in the bedding planes, showing that the joints were filled later. It is probable, also, that the ore in the joints was derived by chemical solution and re-deposition from the bedded ore.

It often happens that no sign of the original stratified character of the deposits is seen, and the ore runs in all directions through the rock. It seems possible that in such cases the ore was originally finely disseminated through the rock, and that subsequent chemical action caused its solution, segregation, and re-deposition in its present form. This process may have given rise to the brecciated novaculite with an iron or manganese cement, which forms one of the most characteristic features of the ore-bearing stratum. The same process of segregation might also help to explain the soft, porous character often observed in the novaculite, in the immediate vicinity of the ore-bearing deposit, since the same rock in the same stratum only a short distance from the ore resumes its hard flinty nature. It is as yet, however, a matter of some doubt whether a segregation of the kind described is not, in many ore-deposits, simply superficial, due to surface agencies without any deep-reaching influence; and it seems possible also that, though the same mineral matter may exist below, it may be in a form which is not available for commercial purposes.

CHAPTER XIII.

THE MANGANESE DEPOSITS OF SOUTHWESTERN ARKANSAS.—*Concluded.*

PULASKI COUNTY.*

General features.—Manganese has been found in the western part of Pulaski county, at various points from ten to fifteen miles west of the city of Little Rock. This region is known as the Fletcher Range, and has been prospected for manganese and iron by the Capitol Land and Mining Company, by Mr. R. W. Worthen, Messrs. Whittemore and Bunch, and others. A large part of the prospecting has been done in the drainage area of Fourche Bayou, a tributary of the Arkansas River; and especially in the neighborhood of McHenry Creek, a small branch of the Fourche.

The localities visited by the Survey are described below. None of them contain manganese in such quantities or of such quality as to allow profitable mining, and the nature of the deposits makes it absolutely useless to attempt to search for workable bodies of manganese ore anywhere in this area.†

The Capitol Land and Mining Company.—The Capitol Land and Mining Company commenced operations in the Fletcher Range in the spring of 1888. Several small pits and tunnels were made, and the site of the town of Martindale was laid out in 1N., 14 W., section 14, the northeast quarter. No ore was shipped and operations were suspended after a few months.

The company controls the following tracts of land all of which are situated in 1 N., 14 W.: section 12, the southwest

* A number of the manganese localities of Pulaski county have been described by T. B. Comstock, annual report of the Geological Survey for 1888, Vol. I. pp. 15-27

† See pages 306-308.

quarter of the southwest quarter; section 11, the south half of the southeast quarter, and the whole of the southwest quarter; section 10, the southwest quarter; the whole of section 14, except the east half of the northwest quarter, and the northeast quarter of the southwest quarter; section 15, the northeast quarter, and the northwest quarter with the exception of the southwest quarter of it; section 23, the northeast quarter with the exception of the southwest quarter of it; section 24, the north half.

This property is situated in the basin of McHenry Creek, which runs diagonally from northwest to southeast through 1 N., 14 W. The stream is bordered on either side by the novaculite and siliceous shale already described, which form rocky ledges rising from one to probably two hundred feet above the creek. In some places the hills encroach on the stream and form narrow gorges, in others they widen out for a few hundred yards and give room for small areas of open land. The property of the Capitol Land and Mining Company, in the part of 1 N., 14 W., in which it is situated, includes the larger part of both the creek bottom and the hills on either side. Bog manganese and iron ores exist in many places along the creek, while in the hills small quantities of manganese ore and brown hematite occur in place in the rock.

(1) The bog ores.—The so-called "bog manganese" occurs in association with a greater or less quantity of clay and angular and rounded fragments of novaculite and shale, from a fraction of an inch to several inches in diameter. The manganese is generally black, earthy, and soft, though in some places it is compact and massive, and in the form of hard kidney-shaped and stalactitic bodies with glossy black surfaces. The latter variety, however, is rare. Generally the manganese forms the cement of a conglomerate with the rock fragments and pebbles just mentioned; and there are all gradations from an ore without rock and pebbles to one in which these compose over half the mass. The manganese has sometimes impregnated the rocks, turning them black, and often the clay is impregnated in the same way by manganese and converted into a light, earthy, soft mass, in which the black manganiferous parts pierce the lighter

colored parts in irregular "stringers" and nests. Frequently the manganese is impregnated with iron, and in some cases runs into a bog iron ore, which has the same general character as the bog manganese, except that it differs in its brown color. In such cases numerous ferruginous or chalybeate springs rise to the surface depositing a brown sediment of hydrous sesquioxide of iron.

The thickness of this bog deposit varies from a few inches to probably ten feet. Where pits have passed through it, it is usually found to be underlain by a gray clay with fragments of rock similar to those associated with the ore. The bog ore protrudes into, and recedes from the underlying bed in a very irregular manner, in some places running down into it for several feet, in others thinning out and allowing it to appear on the surface. The ore deposit represents simply a bed of clay and gravel derived from the erosion of the surrounding hills, and impregnated with manganese and iron from springs, and possibly also from surface waters draining off the surrounding hills.

These deposits in some places occur in the bed of the creek, in others in the low banks and fields on either side, and they also often crop out in the bottoms of the ravines that open upon the creek from the hills. The deposits have been traced at intervals from near the mouth of McHenry Creek for six miles above, but most of them occur along the part of the creek extending from the central part of section 24 in a northwest direction to the western part of section 14, a distance of about a mile and a half. Above and below this area the clay of the creek bed is occasionally discolored by manganese and iron, but does not contain any considerable quantities of those materials.

In some places where the ore is free from clay and rock, it is of good quality, being high in manganese and low in both silica and phosphorus, but such places are rare and limited in extent. Generally the ore contains an injuriously large quantity of silica, even when freed from the rock. This is to be expected from the very mode of derivation of the ore by the impregnation of a highly siliceous clay with manganese. The ore is not only

highly siliceous, but it passes abruptly into an iron ore of the same siliceous character; and the latter ore is in far larger quantities than the manganese. The following analyses show the composition of the bog ores. All the samples analyzed are from the property of the Capitol Land and Mining Company with the exception of No. 4, which is from the Whittemore and Bunch tract described on page 332.

Analyses of bog manganese and iron ores from McHenry Creek, Pulaski county.

No.	LOCALITY.	OWNER.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.
1	1 N.,14 W.,s'c 24,SE.,NW	Capitol L. & M. Co.....	59.68	3.09	4.83	0.001	.....
2	" " " " "	" " "	27.34	2.88	42.83	0.116	1.42
3	" " " " "	" " "	8.08	11.82	63.19	0.270	3.67
4	" " sec. 14,NE.,SW.	Whittemore & Bunch..	1.62	27.07	46.37	0.470	3.26
5	" " " 24, NE.....	Capitol L. & M. Co.....	0.89	33.80	44.91	0.160	3.02

The samples for the above analyses were so selected as to show the transition from a bog manganese ore to a bog iron ore. In each sample the larger fragments of rock were removed, and the impurities that remained were such as would be retained in the ore if it was crushed and washed.

Sample No. 1 is from a small stripping on the south bank of McHenry Creek. It represents a picked sample of the very best ore that could be found on the creek. Only very small quantities of such ore occur and the amount is of no commercial importance.

Sample No. 2 is from the same locality.

Sample No. 3 is an average sample from the clearance made for the location of a smelter and from the surrounding openings.

Sample No. 4 is from the Whittemore and Bunch claim in the field of John Mann, on the south side of McHenry Creek.

Sample No. 5 is from a small exposure on the north side of McHenry Creek and not far from the location of samples Nos. 1 and 2.

The first analysis (sample No. 1), which, as just stated, represents a carefully picked specimen, shows an excellent ore;

the second analysis shows a very poor ore; and the rest show materials which are absolutely worthless.

The bog ore deposits have been prospected and stripped of their covering of soil in several places on the property of the Capitol Land and Mining Company. Among these places are:

(*a*) 1 N., 14W., section 24, the southeast quarter of the northwest quarter. Here the ore has been stripped on the south bank of the creek, at the foot of the hills, over an area of about fifty feet square. It is of better quality than that seen on any other part of the property. The composition of the best of it is represented in the first two analyses given above. It rapidly blends into a much poorer ore.

(*b*) 1 N., 14 W., section 24, the southeast quarter of the northwest quarter. Several strippings have been made here on the north side of McHenry Creek, showing the bog ore that is represented in analysis No. 3 of the above table. One of the strippings is at the place intended for a smelter. The ore is of a rusty black color and probably underlies several acres along the creek in this locality. It occurs in patches in the clay and gravel. It is probably several feet deep, though its exact thickness cannot be seen.

(*c*) 1 N., 14 W., section 24, the southwest quarter of the northeast quarter. The bog ore crops out here in the field of A. J. Hutchinson, on the north side of McHenry Creek. It is soft, impure, and contains a considerable quantity of iron and pebbles. A pit, now filled with water, is said to have been sunk into it for two feet, at which depth the underlying clay was reached.

(*d*) 1 N., 14 W., section 24, the northeast quarter. A small exposure of a bright red bog iron ore is seen here in a field on the north side of McHenry Creek. Its composition is shown in analysis No. 5 of the above table.

(*e*) Martindale.—In the immediate vicinity of the site of the proposed town of Martindale in 1 N., 14 W., section 14, the northeast quarter, bog manganese and iron ores have been stripped in several places. They are of the same general character as the deposits already described and do not require

further mention. Numerous other similar deposits occur along McHenry Ceek, both above and below Martindale.

(2) The ores in the hills.—In the hills both to the north and south of the creek, numerous small openings have been made, and some of them show manganese and iron in place in the rock. On the summit of the ridge that runs along the south side of the creek from 1 N., 14 W., section 24, the northwest quarter, to section 15, the northwest quarter, several cross cuts have been made in the gray novaculite. They sometimes show very small quantities of manganese and iron, but usually not more than a stain. In section 24, the southwest quarter of the northwest quarter, a shaft has been sunk on rock impregnated in this manner. The shaft is now (Dec., 1890) nearly filled with water, but it is said to be about 25 feet deep. In section 24, the northwest quarter of the northwest quarter, a drift was run for about 50 feet into the siliceous shale in the bluffs on the south side of McHenry Creek. No ore was found.

A few cuts have also been made in the ridge on the north side of the creek, extending from 1 N., 14 W., section 13, the eastern part, to section 11, the southwest quarter, and passing north of the site of Martindale. The ore occurs in this ridge in a manner similar to that already described. A short distance north of Martindale a cut about fifty feet long and five feet wide has been made in a siliceous shale, which has partly decayed into a hard clay. The cut has exposed very small quantities of brown hematite, in pockets and discontinuous layers, from one to five feet in length and from one to five inches in thickness.

The Whittemore and Bunch tracts. (*Iron.*)—Messrs. Whittemore and Bunch own several tracts of land and several mineral claims in the western part of Pulaski county. Among the openings that have been made on them are those described below:

(1) Iron.—1 N., 14 W., section 14, the northeast quarter of the southwest quarter, and the southeast quarter of the northwest quarter. This property is on the banks of McHenry Creek. A small prospecting pit has been sunk on a deposit of impure bog iron ore, but no considerable work has been done. The ore is of a rusty brown color and contains numerous frag-

ments of rock and inclusions of clay. An analysis of the ore given on page 330 shows it to be of no commercial value. Further details about this class of ore are given on pages 328–331.

(2) Iron.—1 N., 13 W., section 19, the north half. Messrs. Whittemore and Bunch have prospected a claim in this locality, and a small cut about twenty feet long and six feet wide has been made in the siliceous shale. The rock has a rusty stain and occasionally contains lenticular layers of iron ore, from 1 to 3 inches in thickness. The ore is in such small quantities as to be of absolutely no commercial importance.

The R. W. Worthen tracts. (*Manganese and iron.*)—Mr. R. W. Worthen owns several tracts of land as well as several claims in 1 N., 14 W., and 1 N., 13 W. Among the openings that have been made are those described below:

(1) Manganese and iron.—1 N., 14 W., section 24, the south half. Two small pits have been sunk in the northeast quarter of the southwest quarter of this section. They are in the novaculite on the summit of a hill immediately south of McHenry Creek. They show manganese ore and brown hematite in small irregular seams and pockets, from one to three inches in thickness, scattered through the rock. Sometimes the two ores are intimately mixed as a manganiferous iron ore, at other times they occupy different places along the course of the same seams. Neither ore is in workable quantities.

In the southeast quarter of the southeast quarter of the same section, a shallow pit, about ten feet square, has been made in a gray novaculite, near the top of a hill. The novaculite is impregnated with seams and nests of brown hematite from one to three inches in thickness, forming a network through the rock. These are seen on all sides of the pit, and are traceable elsewhere on the surface of the hill in greater or less quantities. The ore often forms the lining of hollows in the novaculite, and in such cases is frequently covered with a black incrustation. The ore is hard, very siliceous, sometimes contains crystals of quartz, and is too poor in quality and too small in quantity to be of any commercial value.

(2) Iron.—1 N., 13 W., section 19, the southwest quarter

of the southwest quarter. Here the same brown hematite occurs as at the last place, except that the seams are more numerous and frequently form circular layers around masses of novaculite. The ore-bearing rock forms the crest of a ridge and is bordered on either side by gray siliceous shale. The ore is not in quantities sufficient to be of any commercial value.

(3) Manganese and iron.—1 N., 13 W., section 19, the northwest quarter of the southwest quarter. Here a small pit has been made on a hard gray novaculite impregnated with seams of manganese ore and brown hematite, from a fourth to one inch in thickness, and with nests of the same materials from one to six inches in diameter. Both ores are in very small quantities.

(4) Manganese.—1 N., 13 W., section 33, the northwest quarter of the northwest quarter. A shaft, now mostly filled with water, is said to have been sunk here for twenty-seven feet. Fragments of the material it passed through are seen on the dump. They consist of a soft gray novaculite stained with manganese, giving rise to a black mass of the same granular consistency as the rock and often mistaken for good ore. A less impure ore, however, occurs in thin seams from a fraction of an inch to two inches in thickness, occupying cracks and joints in the rock. Not much iron is found with the manganese, though sometimes the latter is stained rusty and occasionally thin layers of glossy limonite are seen. The shaft is said to have passed through nine feet of this kind of rock, but the ore in it is too siliceous to be of commercial value. The following analyses show its composition. The first analysis is of the less impure kind; the second is of the stained novaculite which is generally mistaken for good ore:

	(1)	(2)
Manganese	40.89	13.31
Iron	2.17	0.87
Silica	29.30	74.79
Phosphorus	0.003	0.015

The silica in the first sample is too high to permit the ore to be classed as anything but of very low grade; while in the second, the 74.79 per cent of silica renders the material absolutely worthless.

Exposures similar to those described are seen in numerous other places on Mr. Worthen's lands in 1 N., 13 W., sections 29 and 32, but do not require further mention. In section 29, the northeast quarter of the southeast quarter, the novaculite ridge is often stained along its summit with iron and occasionally a little manganese, but no commercially important quantities of either ore are seen.

GARLAND COUNTY.

General features.—The novaculite ridges run through the southern part of Garland county, and manganese is found in them in several places. No mining has been done, however, though a few places have been prospected and a number of claims have been taken up. The manganese is in small quantities of no commercial value.

Hot Springs.—The waters of the Hot Springs* issue from the gray novaculite and deposit a calcareous tufa on the upturned edges of the rocks. This deposit is sometimes ten feet or more in thickness and cements fragments of rock from the hillsides. Manganese is frequently found impregnating this material, either as a black coloring matter or as thin earthy seams, running through the mass and often cementing the rock fragments. Manganese also occurs in thin seams and nests in the gray novaculite which forms the mass of the hills in the neighborhood. The ore in both rocks occurs in quantities too small to be of any value.

The Rector and Roulston claim No. 1. (*Iron.*)—The Rector and Roulston claim No. 1 is in the southeastern corner of Garland county, in 4 S., 19 W., section 3, the south part of the southeast quarter. It is on a ridge running in an east-west direction and composed in its central part of a gray novaculite, bordered on either slope by black or gray siliceous shale. The rocks dip almost vertically. Iron ore in the form of a porous brown hematite is found on the southern slope of this ridge, in the gray novaculite at or near its contact with the shale. The ore is not seen in place in the rock, but masses of it from one to a hundred pounds in weight, as well as large slabs of rock carrying masses

*These waters are treated by the State Geologist in Vol. II. of the annual report the Geological Survey for 1890.

of ore, are plentiful along the line where the deposit would crop out were it not covered by loose material. Judging from the character and distribution of these masses, the ore in the bed rock probably runs through the novaculite in seams and bunches from one inch to several feet in thickness, and the rock thus impregnated probably occupies a belt from twenty-five to thirty-five feet in width, running in the direction of the ridge and bordered on either side by barren rock.

It is not probable that this iron ore will be found in quantities sufficient to work at a profit.

The accompanying analysis shows the ore to be of good quality in its high percentage of iron and low percentage of silica, but it contains an injurious amount of phosphorus. The sample analyzed contains no manganese, but it is not impossible that small and unimportant quantities of manganese may be found in the same deposit elsewhere on the property.

Analysis of iron ore from the Rector and Roulston claim, Garland County.

Metallic iron	57.54
Metallic manganese	none.
Silica	2.96
Phosphorus	0.67
Alumina	0.22

Three hundred yards north of this ridge, is another parallel though somewhat lower ridge. On both of its slopes, at the lines of contact of the gray novaculite which forms the upper part, with the siliceous shale which forms the lower parts on both sides, are exposures of iron ore similar to that just described. Small masses of a hard manganese ore occur with the iron ore, but both ores are in very limited quantities.

The Rector and Roulston claim No. 2. (Iron.)—The Rector and Roulston claim No. 2 is in the southeast corner of Garland county, less than half a mile north of the line of Hot Spring county, in 4 S., 19 W., section 10, the south half. Iron ore is found in the same rock and in the same position as at the last localities described. The ore itself, however, differs slightly from the ore at those places. It is of a bright vitreous nature, frequently honeycombed with small cavities. It occurs in thin seams and

pockets, from a fraction of an inch to three inches in thickness, impregnating the gray novaculite for a width of about ten feet, and often giving the rock a brecciated appearance. This ore-bearing part of the novaculite occurs just above the contact of that rock with the siliceous shale, on the north slope of the ridge. The ore is not seen in workable quantities.

HOT SPRING COUNTY.

General features.—The novaculite ridges run in a general east and west direction through the northern part of Hot Spring county and the extreme northern limits of Clark and Pike counties. In Hot Spring and Clark the ridges are commonly called the Trap Mountains, though they are also known by various individual names. The term Jack Mountain is applied to a noted ridge in Hot Spring county, and sometimes the same name is used to indicate the whole of the eastern part of the Trap Range. Manganese has been found in many parts of this area, but no ore has been shipped, and a few small prospect pits represent all the work that has been done. No workable quantity of manganese ore has been discovered in the Trap Mountains. (See pages 306–308.)

*The Booker claim.** (*Manganese.*)—The Booker claim is in 4 S., 20 W., section 30, the southeast quarter, on what is known as Carbonate Mountain. Carbonate Mountain is one of the most southerly of the east-west novaculite ridges comprising the Trap Mountains in the northern part of Hot Spring county. About three miles north by west from the village of Bismarck, Big Hill Creek cuts through Carbonate Mountain and forms a steep ravine, on either side of which the mountain pursues its east and west course.

On the west side of the ravine, and about forty feet above the level of the creek, a small pit eight feet in depth has been made in the gray novaculite. The rock is brittle and hard, and frequently contains cavities lined with quartz crystals. In the sides of the pit are a number of thin seams and nests

* This property is described by T. B. Comstock under the name of Buena Vista Lode in Vol. I. of the annual report of the Geological Survey for 1888, p. 89.

of manganese ore, from a sixteenth of an inch to one inch in thickness, running through the rock in all directions. Masses of manganese ore four or five inches in diameter are said to have been found. In some places the ore is a crystalline pyrolusite, associated with a harder manganese ore, and sometimes contains more or less iron.

The pit shows a breadth of ten feet of novaculite impregnated with ore; and elsewhere on the surface similar exposures are seen for a breadth of twenty-five feet or more. The belt runs up the slope of the hill and has been opened again in a small pit about fifty feet higher than the last. Thence it continues intermittently along the ridge. Some of the ore is a good quality of pyrolusite, but, so far as seen in the openings, it is in small quantities.

The F. Holstein claim No. 1. (*Manganese.*)—The F. Holstein claim No. 1 is in 4 S., 19 W., section 22, the southwest quarter, and is on the most southerly of the east-west novaculite ridges in this part of Hot Spring county. A small branch of Prairie Bayou cuts through the mountain on this property, and the novaculite bluffs rise to a height of from a hundred and twenty-five to a hundred and fifty feet above the creek. Half way up the side of the bluff a pit, three feet in depth, has been made in the gray novaculite. It has exposed thin seams of pyrolusite, as well as a harder ore, from the thickness of a sheet of paper to half an inch, forming a network in the rock and frequently comprising the cement of a breccia of novaculite fragments. Small quantities of iron pyrites also occur in the rock.

The F. Holstein claim No. 2. (*Manganese.*)—The F. Holstein claim No. 2 is in 4 S., 19 W., section 21, the southwest quarter, a mile west of the last locality, on the same mountain, and in a similar position on the side of a ravine. The manganese occurs in nests and discontinuous seams, from one to three inches in thickness. It is crystalline and is sometimes associated with harder massive ore, the two varieties blending into each other. The manganese is in the gray novaculite near its contact with the black siliceous shale. Similar ores are said to be found between claims Nos. 1 and 2.

The Conley Sullivan claim. (*Manganese and iron.*)—The Conley Sullivan claim is in 4 S., 20 W., section 26, the northwest quarter of the southeast quarter, on the north side of an irregular rocky hill of gray novaculite. Manganese and iron ore occur together in the rock, and the surface of the hillside is strewn with fragments of both. The manganese is a compact, black, massive ore, porous and often in stalactitic forms. The iron occurs as a brown hematite, often porous and of a brittle, vitreous character. Both ores occur either in separate masses, or in an intimate admixture. Sometimes small stalactitic branches are found which are composed of manganese on the outside and iron ore on the inside. In one place there is seen a solid mass of the mixed ores, in which manganese largely predominates, measuring 30 inches long by 18 inches in width and thickness, and weighing several hundred pounds. Many similar though smaller masses are strewn over the surface; and though, on account of the debris, good exposures of the ore in place in the bed rock cannot be seen, it is possible that a pocket of ore exists here of a larger size than elsewhere in the surrounding region. Its extent, however, has not been proved. The following analysis shows the composition of this ore:

Analysis of manganese ore from the Conley Sullivan claim, Hot Spring county.

Manganese	41.54
Iron	14.15
Silica	1.29
Phosphorus	0.56
Manganese peroxide	60.58

The Henry Little claim. (*Iron.*)—The Henry Little claim is in the western part of the Trap Mountains, in 4 S., 21 W., section 15, the northwest quarter, and is less than half a mile southeast of Lightfoot Springs. A few blasts have been made on this property in a novaculite ledge carrying the same porous and stalactitic iron ore as that found at the Conley Sullivan claim, except that there is little or no manganese with the iron. The ore is often coated with a brilliant red ochre. The thick-

ness of the deposit cannot be seen, as it is mostly covered by debris, but some large masses of ore weighing several hundred pounds have been blasted out. What has already been said as regards the quantity of ore at the Conley Sullivan claim may also be applied here.

The same lead of ore is said to be traceable for four miles east, and two miles west of Lightfoot Springs.

Other localities in Hot Spring county.—Manganese and iron have been found in 4 S., 22 W., section 34. This locality is in the western part of the Trap Mountains, on a novaculite ridge running in a direction a little south of west through the northern half of the section. A hard, steel-blue, massive manganese ore, associated with the usual brown hematite, permeates the rock in thin seams, a fraction of an inch in thickness, though sometimes larger masses from three to five inches in diameter occur. The outcrop can be traced at intervals for more than a mile along the strike of the novaculite, in some places following the south slope of the hill, in others rising to the summit. In places it is only a stain or disappears altogether, appearing again a short distance beyond.

CLARK COUNTY.

Small quantities of iron ore occur in 5 S., 22 W., four miles west of Point Cedar, in the novaculite ridge that runs in a general direction of a little south of west through the extreme northwestern part of Clark county. The ore appears in a sag on the summit of the ridge, and is in quantities too small to be of of any value. It is but little more than a stain.

PIKE COUNTY.

Rundle's Creek. (*Manganese and iron.*)—Rundle's Creek is a small branch of the South Fork of the Caddo River running east through the northwest part of 5 S., 25 W., and bordered on either side by novaculite ridges. In section 4, the southeast quarter of the northeast quarter, on the slope of the ridge immediately north of the creek, small quantities of brown hematite with a little earthy manganese ore occur. The ore forms

the cement of a well developed breccia of novaculite fragments, but composes only a small fraction of the mass. The breccia in places is from ten to fifteen feet in width, but the ore is very limited in quantity. Similar outcrops occur along the slope of the mountain, in the direction of the strike of the rocks, for a mile, and they are said to be traceable for a still greater distance.

In section 4, the southeast quarter, a short distance south of Rundle's Creek and on a spur of the main mountain, there is iron ore associated with small quantities of manganese ore. It occurs in small irregular pockets in the gray novaculite. The iron ore is frequently composed of nodules with a radiating structure and from an eighth of an inch to one inch in diameter. The main ledge is obscured by loose material, but fragments of iron ore from fifty to a hundred pounds in weight are seen. One pocket, in place in the rock, measured between three and four feet across. The quantity of ore is small.

The W. H. Coffman claim. (*Manganese.*)—The W. H. Coffman claim is in 5 S., 25 W., section 9, on a small creek flowing over the gray novaculite. A soft, granular, pyrolusite occurs in thin seams, half an inch and less in thickness, in the bed of the creek, and similar outcrops are traceable along the east side of the creek for about fifty feet.

Ores similar to those already described at the last three places are seen in many parts of the surrounding country, and what has already been said will apply to all of them. They follow the summits and slopes of the ridges, and are represented either simply by a stain or by thin seams and pockets.

Line Mountain. (*Manganese and iron.*)—Line Mountain is a novaculite ridge running east and west approximately on the boundary line of Pike and Montgomery counties, two miles south of Fancy Hill Post-office. Manganese and brown laminated iron ore are found along the southern slope of the mountain, in Pike county. The manganese ore is generally a soft, black mass sometimes, however, in harder, stalactitic forms, and occasionally has a plumose crystallization. The main outcrop is obscured by loose material, but small fragments of both the iron and the manganese ores are scattered at intervals along the

mountain slope, and in one case a mass of the latter ore was seen which measured four inches in thickness and about twelve inches in length and breadth. Similar fragments of ore are said to be traceable along this slope at intervals for seven miles. The quantity of both manganese and iron is exceedingly limited.

The following analysis shows the composition of the ore from Line Mountain:

Analysis of manganese ore from Line Mountain, Pike county.

Manganese	30.93
Iron	9.21
Silica	5.86
Phosphorus	0.32
Manganese peroxide	42.09

Other localities in Pike county. (*Iron.*)—In the northern part of 5 S., 27 W., and on the south slope of the most southerly of the novaculite ridges in the northern part of Pike county, is a series of soft, earthy sandstones, with interbedded red and gray shales. Numerous outcrops of brown hematite occur in the sandstone, in one place forming a bed three feet thick, in another forming small pockets and discontinuous layers. No manganese was seen. Ores similar to those described but in smaller quantities are traceable westward on the slope of the same mountain for three miles, to within a mile of the Little Missouri River.

MONTGOMERY COUNTY.

General features.—The novaculite ridges pass through the southern part of Montgomery county, from Mazarn Creek on the east, across the Caddo River, to the head of the Little Missouri River on the west. In the eastern part of this area, the novaculite is represented by a series of ridges which curve around and join each other at their extremities, thus forming one continuous but very tortuous ridge. This structure is directly dependent on the folding of the rocks, resulting from the disturbance to which the region has been subjected, as explained in the last chapter. A few minor disconnected ridges also occur. In the region from

Mazarn Creek to Caddo Gap, on the Caddo River, but little manganese has been found. Several deposits of iron ore occur in the position usually occupied by manganese, and in such places claims have often been taken up on the supposition that the ore was manganese. This has given an erroneous idea of the quantity of the manganese, though even the iron ore is limited in amount.

At Caddo Gap the Caddo River cuts a deep gulch through the main novaculite range. Thence west to the Little Missouri River, the ridges become more and more numerous, until at the head waters of that stream the most rugged part of the novaculite belt is reached. The head waters of the Little Missouri River rise partly in the southwest corner of Montgomery county and partly in the southeast corner of Polk county, but the main stream is a short distance across the line in the former. The region has been greatly disturbed and the river follows a circuitous southerly course through the series of east and west ridges that bar its way. At times it flows parallel to the ridges for short distances and then turns sharply to the south, plunging through a series of rocky passes from which the white novaculite rocks rise in steep bluffs. The river emerges from the mountains in the extreme northwest corner of Pike county, passing its last canyon between two of the most characteristic bluffs of the region, and bears off thence through the less rugged country to the south, finally discharging its waters into the Ouachita River. No deposits of manganese ore which can be worked in any way but on a small scale have been found in Montgomery county, and only very few of them can be worked at all. (See pages 306–308.)

The Meyer Creek claims. (*Manganese and iron.*). —Meyer Creek is a small stream rising southwest of Crystal Springs and flowing southeast into Mazarn Creek. In 3 S., 22 W., section 16, it cuts a deep gorge through the novaculite ridge which passes in a zigzag course southwest through this part of Montgomery county. On the part of the ridge that runs west from the creek, a few fragments of brown hematite, occasionally associated with small quantities of hard, black manganese ore have been found, and several claims have been taken up. Similar

materials are occasionally seen in place in the novaculite, but the quantity is exceedingly small and of no commercial importance.

The Bud Jones claim No. 1. (Iron.)—The Bud Jones claim No. 1 is in 3 S., 23 W., section 22, the southeast quarter of the northeast quarter. This tract is about five miles west by south from the claims already described on Meyer Creek, and on a ridge rising over four hundred feet above Mazarn Creek, which is less than a mile to the southwest. The gray novaculite forms the crest and upper slopes of the ridge, and the siliceous shale forms the lower slopes. On the south side of the mountain, in the gray novaculite, and just above the contact of that rock with the siliceous shale, is a deposit of iron ore.

The ore is massive, of a bright submetallic lustre, steel-gray color, and a reddish-brown streak. It has the physical properties of hematite, but chemically it differs from it in containing 8.05 per cent of water. It has already been described on page 317. The outcrop is mostly obscured by loose material, but where exposed, it has a maximum thickness of two feet. If it were stripped, it would probably be found wider in some places. The outcrop is traceable for about a hundred yards along the slope of the hill, and strikes in an easterly direction towards the summit. It could probably be traced farther were it not covered by debris. The ore occasionally contains layers or masses of gray novaculite, and sometimes forms the cement of the breccia of novaculite fragments. It is undoubtedly an interbedded deposit at the contact of the novaculite and siliceous shale, or in the former near the contact. In the hollow at the foot of this mountain are found numerous masses of this ore that have rolled from above, some of them weighing several hundred pounds.

The accompanying analysis shows the composition of the ore on this property:

Analysis of iron ore from the Bud Jones claim, Montgomery county.

Iron	61.99
Manganese	0.04
Silica	1.53
Phosphorus	0.20
Water	8.05

The analysis shows the ore to be of good quality in its high percentage of iron and low silica, but it contains an injurious quantity of phosphorus.

In the siliceous shale that borders the gray novaculite on either side, are found interstratified beds of ordinary brown hematite, from one to three feet in width, generally mixed with more or less shaly material. Sometimes the beds are entirely replaced by shale, while perhaps a few hundred yards farther on they appear again, the transition being often sharp. The relation of the different rocks to the different kinds of iron ore found on this property is shown in the accompanying figure, which represents a section in a north-south direction across the ridge on which the claim is situated. The deposit marked D is the ore described first, of which an analysis is given above. The deposits marked C represent the brown hematite in the siliceous shale. The continuation of the ore below the surface, as represented in the figure is imaginary, as no mining has been done, but it shows the general direction of the downward extension of the deposits. The thickness of the ore-beds as represented in the figure is greatly exaggerated, this being necessary in order to make the position of the deposits clear.

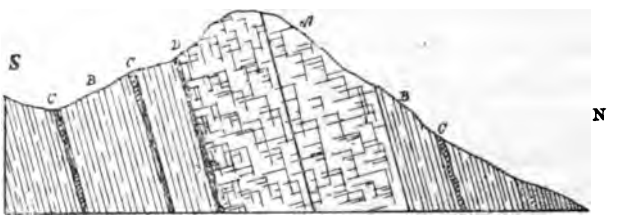

Figure 25. *North-south section through the Bud Jones claim, Montgomery county, showing the occurrence of the iron ores.*

A. Gray novaculite.
B. Siliceous shale.
C. D. } Iron ores.

Horizontal scale: 1 inch=800 yards. Vertical scale: 1 inch=400 feet.

The Bud Jones claim No 2. (Iron.)—The Bud Jones claim No. 2 is in 3 S., 23 W., section 23, the southwest quarter. It is less than a mile south-by-east from the last locality. Fragments of iron ore similar to the first kind described at the last place are

scattered over the surface. The ore is not seen in place, as the main deposit is concealed by loose material. The surface fragments are frequently made up of a mass of thin stalactitic branches, from a sixteenth to a quarter of an inch in diameter.

The Bud Jones claim No. 3. (Iron.)—The Bud Jones claim No. 3 is in 3 S., 23 W., section 29, the north half. This claim is on the north side of a novaculite ridge and half way up its slope. The gray novaculite forms the summit and the upper half of the ridge, and the siliceous shale forms the lower slope. The rocks all strike east-west and dip steeply to the north. A seam two and a half feet in thickness of a porous brown iron ore occurs in the gray novaculite, and is often coated with a brilliant red ochre. Unlike most of such exposures, however, the larger part of the ore does not lie in the bedding of the rock, but dips at about 70° east, and strikes north and south directly across the stratification. On the slope of the ridge, the gray novaculite forms an almost vertical ledge for ten or fifteen feet above its contact with the siliceous shale, and in the face of this ledge a cross section of the ore deposit is well exposed. Twenty feet above the shale, the deposit thins out to a few inches in width. Sections of similar though smaller deposits, from one to twelve inches in thickness, are seen in the face of the ledge. Sometimes thin layers or small pockets of the same kind of ore follow the contact of the two rocks in the normal interbedded manner. The other deposits probably represent crevices filled with iron ore derived from originally interbedded ores in the novaculite. The following analysis shows the composition of this ore:

Analysis of iron ore from the Bud Jones claim, Montgomery county.

Iron	54.54
Manganese	0 30
Silica	0.84
Phosphorus	1.79

The Dunney claim. (Iron.)—The Dunney claim is in 3 S., 23 W., section 30, the northeast quarter of the northeast quarter. It is about a half mile west of the last claim, on the summit of the same gray novaculite ridge. The ore deposit consists of a breccia of soft, angular, novaculite fragments, from a fraction

of an inch to six inches in diameter, cemented in a bright submetallic, steel-gray iron ore.* The ore is generally in the form of thin seams, a fraction of an inch in thickness, cementing the rock fragments; though sometimes pure masses several inches in diameter are seen. Occasionally it is in mammillary or stalactitic forms, or in small, flat nodules stuck to the novaculite fragments. The breccia runs along the ridge, but rapidly thins out in either direction.

An examination of the breccia shows that, though the fragments of the rock are separated by thin layers of ore, the angles of any two pieces directly opposite each other would almost always fit together if the ore were removed. It is probable, therefore, that the brecciation is caused by the shattering of the rock in place, and not by the cementing together of novaculite fragments indiscriminately mixed together.

The Golden Gate claim. (*Iron.*)—The Golden Gate claim is in 3 S., 23 W., section 31, the northwest quarter. Here the same breccia is seen as at the last place, except that the iron ore has a brown, dull, earthy, porous appearance instead of a bright submetallic lustre; a fact, however, which may be due to surface weathering. The thickness of the outcrop is not seen on account of the covering of loose material, but fragments of ore are scattered for a distance of over two hundred yards along the north slope of the mountain. Occasionally masses of pure ore, from one to two hundred pounds in weight, are found.

Township 4 S., 24 W. (*Manganese and iron.*)—The main novaculite ridge passes through this township from northeast to southwest, in a series of irregular folds that at times run parallel to each other for two or three miles, and then, curving around again, run off in the opposite direction. This is one of the best examples seen in the novaculite region of the relation of the topography to the geologic structure: from the summit of one of the higher ridges, the effect of the disturbance that brought the rocks into their present position, can be clearly traced along each ridge and around the semicircle formed where they curve in the

* This ore is the one referred to on page 317 as representing the mineral turgite.

opposite direction.* The ridges rise from five hundred to six hundred feet or more above the Caddo River. Small quantities of iron ore are found in the novaculite at many places in these hills, and still smaller quantities of manganese ore also occur in associations similar to those already described. Both ores are in quantities of no importance whatever and do not require further mention.

Caddo Gap.—Caddo Gap is a deep gorge through which the Caddo River, in the western part of 4 S., 24 W., crosses one of the main novaculite ridges. Beyond, to the west, the ridge rises again to a height of five hundred and fifty feet, and continues towards the head waters of the Little Missouri River.

In the bluff on the west side of the Caddo River, immediately north of the village of Caddo Gap, a stain of iron occurs in the novaculite at the contact of that rock with the shale, on both sides of the ridge, and occasionally small masses of solid ore are seen. These exposures are traceable thence westward, but the quantity of ore is insignificant and of no commercial importance.

"*S Crossing.*" (*Iron.*) — Such occurrences as those just mentioned are again seen on a trail crossing the ridge about two miles west-by-north from the village of Caddo Gap. The trail passes through a circuitous gorge, from which the name "S Crossing" has been derived. In places on the south slope of the mountain, on this trail, the novaculite is stained a deep rusty color, and contains thin seams and pockets of the iron ore already described. These vary from one to eighteen inches in thickness and occur in a belt of novaculite about fifty feet wide. They are not seen in workable quantities.

North Mountain.† (*Manganese and iron.*)—North Mountain is the name locally applied to the novaculite ridge running north of west in 4 S., 26 W., about two miles north of Fancy Hill Post-office, and is the continuation of the ridge at Caddo Gap. On the slopes of the mountain the iron and manganese stratum occurs in the gray novaculite near its contact

*See report of L. S. Griswold, Vol. III. of the annual report of the Geological Survey for 1890.

†This name is also applied to several other ridges in the Ouachita Mountains, as will be seen in the descriptions given later in this chapter.

with the shale, and follows the strike of the rocks along the ridge. Both the iron and manganese are in small quantities, the latter especially so, and the ore-bearing stratum is usually marked only by a ferruginous stain or by small seams or bunches of iron ore.

*The Burns claim.** (*Iron.*)—This one of the Burns claims is in 4 S., 26 W., section 18, the southwest quarter, and is on a low foot-hill of the main ridge lying to the north. The gray novaculite forms the south slope and the siliceous shale the north slope, their contact coming at the crest of the hill. Along this contact line numerous flat masses of a laminated brown hematite, from three to twelve inches in thickness, are found among the loose rock. Very little stripping has been done and the main body of ore is not exposed, so that the full thickness of the deposit cannot be seen, but the ore is probably limited in extent.

Larger quantities of a similar ore, however, are found in the hollow separating this hill from the mountain to the north, and in one place a bed ten feet thick was seen. In many other places in the neighborhood, both to the east and to the west, similar though somewhat smaller outcrops occur. The ore intermittently blends into the shale and disappears.

Fancy Hill Mountain. (*Manganese and iron.*)—Fancy Hill Mountain is in 4 S., 26 W., section 28, and is a novaculite ridge having a general direction of a little north-of-west and south-of-east. It begins just south of Fancy Hill Post-office and bears thence towards the head waters of the Little Missouri River. On the northeast slope and about three-quarters of a mile west of the post-office, a deposit of mixed manganese and iron ore follows the strike of the ridge. The manganese ore is a hard, black variety, and the iron is in the form of a bright, vitreous, brown ore, often having a honeycombed structure. The two are intimately mixed together, the iron being much the more plentiful; and sometimes nodules of manganese, from a fraction of an inch to one inch in diameter, are cemented in a matrix

* Mr. Burns has a large number of manganese and iron claims in Montgomery and Polk counties, and they are described in the order of their occurrence in these counties.

of iron ore. Sometimes the ores are comparatively free from any admixture of rock, and at other times they form the cement of a novaculite breccia. The total width of the deposit is about twenty feet, and on each side scattered masses and pockets of ore occasionally occur in the novaculite. The ore is rarely seen in place, but numerous large masses of it are scattered over the surface. The ore-bearing stratum forms the crest of a small spur and dips almost vertically. It rapidly grows thin both to the east and to the west.

The deposit represents a pocket of ore much larger than is usually seen in the gray novaculite, but, as shown by the accompanying analysis, it is of poor quality for use in the manufacture of spiegeleisen and ferro-manganese on account of its high percentage of phosphorus; and its association with iron renders it undesirable for many chemical purposes. Its high percentage of peroxide of manganese, however, would for some purposes counterbalance the latter disadvantage.

Analysis of manganese ore from Fancy Hill Mountain, Montgomery county.

Manganese	48.02
Iron	5.55
Silica	0.52
Phosphorus	0.31
Manganese peroxide	71.73

Caddo Mountain. (*Iron.*)—Caddo Mountain bears east and west through the extreme southwestern part of 3 S., 26 W., and into 3 S., 27 W. It runs parallel to, and on the immediate south side of the Caddo River, rising about 400 feet above it. The crest and the upper part of the ridge are composed of gray novaculite, and the black siliceous shale occurs on the slopes. On the summit are numerous outcrops of a black or dark brown iron ore, with a bright metallic lustre, frequently in globular, stalactitic, or mammillary forms. It is in thin seams and pockets, from a fraction of an inch to a foot in thickness, and generally forms the cement of a breccia of novaculite fragments. It de-

composes on the surface into a brown, earthy ore. The mixture of ore and rock is from ten to forty feet in width. It was followed for two miles along the crest of the ridge and is doubtless traceable for a still greater distance. The amount of ore, however, in any one place is small, as the novaculite fragments compose by far the larger part of the ore-bearing stratum. The ore, though sometimes in small pockets free from rock, is generally in the form of thin layers or films in the novaculite.

The Crooked Creek region.—Crooked Creek runs west through the northern tier of sections of 4 S., 27 W., and then turns abruptly to the southeast, flowing thence into the Little Missouri River in the same township. It forms one of the main forks of the Little Missouri River in this region of the head waters of that stream, and its valley is bordered by novaculite ridges. Several small pits have been sunk on the ridges on the outcrop of the manganese- and iron-bearing stratum.

On the top of the more southerly of the two novaculite ridges immediately south of the creek, probably in section 10, a small pit has been sunk on the gray novaculite, showing a hard, black manganese ore, in seams rarely over a quarter of an inch in thickness and generally thinner, penetrating the rock in all directions. The ore is frequently stained with iron, and often small masses of manganese ore enclose kernels of brown hematite.

About a mile east of this exposure, on the south slope of the same mountain, in the gray novaculite, and near its contact with the shale, a small prospect pit has been sunk on iron ore. The ore is found in the rock in small seams and pockets from one to four inches in thickness. It is frequently fibrous, porous or stalactitic, and very often has a brilliantly iridescent surface, showing glossy green, blue, and pink colors. It decomposes on a weathered surface into a brown, earthy ore. The ore on Crooked Creek has nowhere been seen in workable quantities.

North Mountain. (*Manganese.*)—North Mountain is the name locally given to a broken novaculite ridge in the northwest part of township 4 S., 27 W., near the head waters of the Little Missouri River. The ridge rises five hundred and ninety

feet above the level of the surrounding country; and on the upper part of its southeast slope, a small pit has been sunk on a body of manganese-bearing novaculite. The ore is a hard, glossy, black variety, and usually forms the cement of a breccia of angular novaculite fragments from a fraction of an inch to four or five feet in diameter. The ore forms from an eighth to less than a quarter of the mass. In spots, however, there are comparatively pure bodies of it, and a horizontal pocket of such ore about two feet wide runs across the face of the pit. It contains no rock, but a small lenticular layer of clay a few inches thick is included in it. Such masses of pure ore are rare, and of limited extent. Figure 26 represents the face of the opening and illustrates the occurrence of the ore.

The mass of novaculite in the center is surrounded by smaller pieces cemented by manganese ore, and represents simply an exceptionally large component fragment of the breccia. It is noticeable that the angles of almost any two adjacent fragments

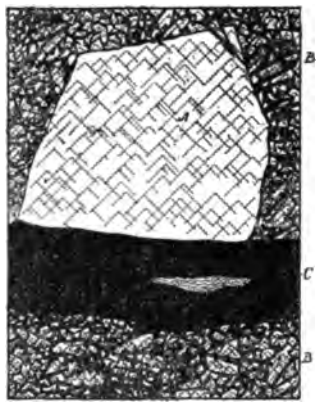

Figure 26. *Section in a pit on North Mountain, Montgomery county, showing a manganiferous breccia in the gray novaculite.*

A. Gray novaculite fragment.

B. Breccia of gray novaculite fragments in a cement of manganese ore.

C. Pocket of manganese ore.

Horizontal and vertical scale: 1 inch=4 feet.

of novaculite would fit into each other if the separating layer of manganese was removed, showing that the breccia has been formed by the breaking of the rock in place and not by an indiscriminate mixing of rock fragments.

The outcrop of the ore-bearing breccia is largely obscured by loose material, but at the point where the pit has been sunk it is about thirty feet wide, and is bordered on either side by novaculite containing only a stain or very thin layers of manganese. It strikes along the face of the mountain in both directions from the opening, but rapidly thins out: fifty feet to the northeast, it is represented only by a stain in the rock; fifty feet to the southwest the same breccia is seen, but it contains very small quantities of manganese. Similar outcrops are said to be traceable along the slope of the mountain for over a mile. The place where the pit was sunk represents a local accumulation of manganese in the ore-bearing stratum, yet even here the deposit is limited. Some manganese could doubtless be taken out at a profit, but the deposit would soon run into ore in quantities too small to work. Four tons of ore are said to have been shipped from this property.

Fragments of laminated brown hematite occur on the slopes of the hills, and have probably come from small interbedded strata of that material in the shales associated with the novaculite.

The Morrell claim. (*Manganese.*)—The Morrell claim is in 4 S., 27 W., section 16, on the east side of the Little Missouri River, at a point where that stream cuts through a novaculite ridge. A small pit sunk near the water level shows a hard, massive, steel-blue manganese ore, often in stalactitic form. The ore is associated with black or brown glossy iron ore, and together they form a pocket from one to three feet in width in the novaculite. The ore frequently contains pockets of red clay.

Little Musgrove Mountain; the Webb Thornton claim. (*Manganese.*)—Little Musgrove Mountain runs east and west in the extreme southwestern part of 4 S., 27 W., and is intersected by the Little Missouri River just above where that stream, issuing from the rocky gorge that it has cut through the novaculite ridges, flows into the less rugged country to the south. The mountain is composed mostly of gray novaculite dipping almost

vertically and forming prominent bluffs on both sides of the river.

The Webb Thornton claim is in section 31, on a steep bluff in the south face of Little Musgrove. A soft, black manganese ore (pyrolusite) occurs here in an equally soft, white novaculite easily crushed in the fingers. The largest exposure of ore is an oblong pocket four inches in its thickest part.

Leader Mountain; the Webb Thornton claim.—This claim is further described on page 358, in the description of Leader Mountain given under the heading of Polk county. The claim is in Montgomery county, but most of Leader Mountain is in Polk, and, as there are several ore-bearing localities on the same mountain, they are more consistently described together.

POLK COUNTY.

The manganese deposits of Polk county are the continuation of the same belt that has already been described in Montgomery county and in the region thence east to Pulaski county. They occur at intervals in a belt of country from five to ten miles in width, and follow the north-of-west strike of the novaculite ridges. The ridges run diagonally through the county from southeast to northwest, crossing the Cossatot River above and below Rhode Post-office, passing less than two miles south of the town of Dallas, and bearing thence to the village of Potter in the northwest part of the county. Still farther to the northwest, the ridges die out in a less rugged country, and the manganese disappears with them.

This mountainous area forms the divide, in this part of the state, between the waters of the Ouachita River on the north and those of the Red River on the south. Board Camp Creek, Big Creek, and numerous other streams, rise in it and flow north into the Ouachita; while the Saline River, the Harris Creek fork and the Brushy Creek fork of the Cossatot River, as well as the main Cossatot itself, rise in the same mountains and flow south into the Red River.

A smaller novaculite area occurs in the neighborhood of Hatton Post-office, in the southwest corner of the county, and bears west towards Indian Territory; but very little, if any,

manganese occurs in it, though specimens of iron ore have been found.

The character of the ridges and the nature of the ores in the novaculite area of this county, have already been treated in the general description of the southwestern Arkansas region in chapter XII., and do not require further mention. The parallelism of the ridges is probably better developed here than anywhere else in the region, and in ruggedness and average height they are second to no other part of the belt. In fact, the highest elevation above the surrounding drainage that has so far been measured by the Survey among all the Ouachita mountains, is the High Peak of Hannah in the southeastern part of the county, which rises a thousand feet (barometric) above the Cossatot River. Other ridges are almost as high and some possibly higher; and it may safely be said that the country from the head waters of the Little Missouri in southwestern Montgomery county to the Cossatot River in Polk county, is the most rugged part of the Ouachita Mountains.

No large deposits of manganese ore have been found in Polk county. The best that have been discovered could only be worked on a very small scale, and even this could be done in but rare cases and for short times. (See pages 306–308.)

McKinley Mountain. (*Manganese.*)—McKinley Mountain runs in a general west-by-north direction from the head waters of the Little Missouri on the east to beyond the Cossatot on the west, and rises in some places over seven hundred feet above the surrounding level. The crest and upper slopes are composed of gray novaculite, the lower slopes of the overlying siliceous shale. Almost on the line of Polk and Montgomery counties it is cut through by Straight Creek, a tributary of Long Creek, the latter a branch of the Little Missouri River. Straight Creek passes through the mountain, in a deep gulch, on either side of which the novaculite forms steep bluffs.

A small pit has been sunk in the novaculite on the western side of this pass, in 4 S., 28 W., a few hundred yards west of the Montgomery county line. The pit shows manganese ore scattered irregularly and in limited quantities through a

breadth of about six feet of the rock; and, in some places, the ore-bearing part of the rock is possibly still wider. The ore is a hard, compact, steel-blue variety frequently stained yellow or red by iron. It occurs throughout the rock in small seams and pockets, from a fraction of an inch to four inches in thickness. In some places the ore blends into the novaculite, turning it a deep black; in other places the line of separation is sharp and well defined. The following analysis shows the composition of this ore:

Analysis of manganese ore from McKinley Mountain, Polk county.

Manganese	49.24
Iron	2.04
Silica	2.98
Phosphorus	0.38
Manganese peroxide	71.41

West of this opening the ore-bearing stratum is traceable along the mountain at intervals to beyond the Cossatot River, but the ore where seen is in even smaller quantities than in the locality just mentioned.

He Mountain. (*Manganese and iron.*)—He Mountain is a novaculite ridge in 4 S., 28 W., south of, and parallel to McKinley Mountain, and separated from it by a ravine which forms the valley of Long Creek. Manganese is found on the summit of the mountain, in Polk county, a little over a mile west of the Montgomery county line.

A small pit three feet deep has been sunk on the ore, which is in small seams and pockets, rarely over two or three inches in thickness. The exact width of this ore-bearing part of the novaculite cannot be seen, but the pit exposes a breadth of about six feet, and it is probably considerably wider. The ore is scattered through the rock in limited quantities. It is a hard, massive, steel-blue variety, frequently having a concretionary structure and a mammillary surface, and is generally associated with more or less massive brown iron ore. The latter often encloses nodules of manganese, or forms the outside layer

of pockets of that ore. There are often small cavities in the novaculite, from one to six inches in diameter, lined with layers of iron and manganese ores. In some places both ore are sharply separated from the novaculite, in others they blend into it, staining it brown or black.

To the west of this locality, similar outcrops are seen intermittently for a distance of half a mile along the mountain, in some places covering the surface with loose fragments of mixed ore and rock; in others disappearing altogether and giving place to barren novaculite.

Coon Creek. (*Manganese and iron.*)—Coon Creek is a tutary of Long Creek and flows west along the south side of He Mountain. In a novaculite hill bordering this creek on the south, half a mile southwest of the He Mountain locality just described, and in Polk county, 4 S., 28 W., another small pit has been opened on a deposit of manganese and iron. Both ores are in about equal quantities, and both are very much like those described on He Mountain. They either form the cement of a brecciated novaculite, or occur as thin layers, nests, or pockets throughout the rock. The largest mass of ore seen came from one of these pockets and was two feet in diameter. Such masses, however, are rare.

Briar Creek Mountain. (*Manganese and iron.*)—Briar Creek Mountain is in 4 S., 27 and 28 W., and runs a little north of west between Coon Creek on the north and Briar Creek on the south. To the east, it passes out of Polk county into Montgomery, bearing off to and beyond the Little Missouri River. A stain of iron and manganese and occasionally small masses of the ores occur in the gray novaculite on the part of the mountain lying in Polk county, and probably these same occurrences extend into Montgomery county; but no important quantity of either ore was seen.

Leader Mountain. (*Manganese and iron.*)—Leader Mountain runs a little north-of-west in 4 S., 27 and 28 W., partly in Polk county and partly in Montgomery. It is south of and parallel to Briar Creek Mountain, and is separated from it by Briar Creek, a tributary of the Little Missouri River. The mountain com-

mences at the Little Missouri River and passes thence to the waters tributary to the Cossatot River. A number of claims have been taken up on exposures of the iron and manganese stratum along its course, several of which are described below:

(1) The Webb Thornton claim. (Manganese.)—The Webb Thornton claim is on the eastern part of this ridge in 4 S., 27 W., in Montgomery county. A pit three feet deep has been sunk on a deposit of manganese in the gray novaculite, and five hundred pounds of ore are said to have been shipped. The manganese is a fine grained, soft, crystalline ore often appearing in plumose forms. It occurs as the cement of a brecciated novaculite and forms from a tenth to as much as two-thirds of the whole mass. Occasionally the manganese is stained with a little iron, but much of it is comparatively free from that impurity.

The pit shows a width of about five feet of this breccia, and though the same ore is seen on either side, it is in very much smaller quantities. The deposit runs along the top of the mountain, but thins out in a short distance in both directions, and is represented either by simply a stain or by thin layers of ore in the novaculite.

(2) The J. Guy Lewis claim. (Iron.)—The J. Guy Lewis claim is on Leader Mountain, about four miles west of the Thornton claim, and two and a half miles west of the line between Polk and Montgomery counties. A small cut has been made on a deposit of hard, brittle brown hematite, of a shaly structure. It occurs as pockets and lenticular beds in the novaculite, the largest seen being a pocket two feet thick. Such deposits are scattered irregularly through the rock on the summit of the mountain over a breadth of about twenty feet. The ore is traceable in intermittent outcrops for half a mile east and west from the cut, and also occasionally beyond these limits.

Sometimes a few small masses of hard, steel-blue manganese ore occur in the iron ore, especially at its contact with the country rock.

Pointed Rock tunnel. (*Iron.*)—Pointed Rock tunnel is in 4. S., 28 W., section 19, and is the property of the Arkansas

Development Company. A deposit of hard, laminated brown hematite occurs here, interbedded in gray and black siliceous shale. The rocks stand vertically or dip at angles of 70° to 80° to the north, and form part of a low hill. A tunnel has been run in at the foot of the hill, just above the level of a small creek, and follows the iron ore in the direction of the strike of the rock for about a hundred feet. The ore occurs in a series of parallel strata from one to twelve inches in thickness, separated by similar strata of shale, or of clay which has resulted from the decomposition of the shale. The northern part of the hill is composed of the gray novaculite, and the ore occurs near the contact of the shale with that rock. The rocks strike across the hill, and the ore can be traced a distance of a quarter of a mile over the summit and down to a creek on the other side. The alternating strata of iron ore and shale occupy together a belt varying from twenty to fifty feet in width. Sometimes the ore in a given stratum runs out and is represented by rock for a few feet, but it usually appears again beyond. In places, the combined thickness of all the ore strata, if brought together, would amount probably to over five or six feet; in others, it would not be a quarter of that thickness.

Tall Peak Mountain. (*Manganese.*)—Tall Peak Mountain forms part of a long novaculite ridge known as Raspberry Mountain, which runs in a general direction a little north of west

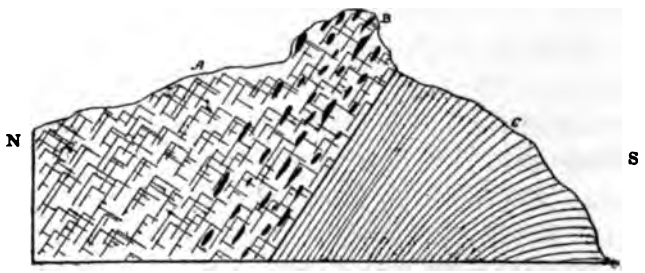

Figure 27. *Section on the north slope of Tall Peak Mountain, Polk county, showing the occurrence of manganese ore in the gray novaculite.*

A. Gray novaculite.

B. Manganese-bearing part of the novaculite. The black parts represent ore.

C. Siliceous shale.

Vertical and horizontal scale: 1 inch—35 feet.

across the head waters of the Saline River and the Harris Creek

fork of the Cossatot River. On the lower part of the northern slope of Tall Peak Mountain, on a claim controlled by the Arkansas Development Company, in 4 S., 29 W., section 24, the gray novaculite is impregnated with manganese for a width of about twenty feet. The ore-bearing part of the novaculite is at the contact of that rock with the shale, and protrudes in a low ledge above the surrounding surface. Its relation to the different rocks is shown in the accompanying figure, which represents a north-south section across a part of the claim.

The ore is in pockets and lenticular layers scattered through the rock, the largest seen being two feet long by from three to six inches in thickness. It occurs both in the form of a hard, massive, steel-blue ore and as a finely crystalline variety, the crystals frequently being grouped in a plumose form, and having a brown streak. Occasionally the manganese contains small quantities of iron, but it is generally comparatively free from that impurity.

On the west the ore-bearing stratum disappears under the gravel of a small creek; on the east it rapidly thins out on the slope of the mountain and is replaced by the pure, gray novaculite.

The usual strata of brown hematite, from one to twelve inches in thickness, occur in the siliceous shale shown in the figure to the south of the manganese. A tunnel was run into this rock with the intention of reaching the manganese, but was not continued far enough to do so. At the mouth of the tunnel the shale is almost horizontal, but to the north it rapidly curves around, and when it reaches the novaculite it is dipping at the same steep angle as that rock. The shale has, in many places, been decomposed into a fine gray clay containing layers of the unaltered rock. The following analysis shows the composition of the manganese ore on this property:

Analysis of manganese ore from Tall Peak Mountain, Polk county.

Manganese	52.16
Iron	4.00
Silica	0.24
Phosphorus	0.39
Manganese peroxide	77.60

Brushy, Prairie, and South Mountains. (*Manganese.*)—These mountains run in the same direction as Raspberry Mountain, and lie in parallel ridges to the east and southeast of it. They are all novaculite ridges, and small quantities of manganese, either in the form of a stain in the rock or of thin seams, are seen in various places on them.

Gillam Springs. (*Iron.*)—Gillam Springs is in 4 S., 30 W., section 22, the southwest quarter of the northwest quarter, on the Dallas and Centre Point wagon road, twenty miles, by the road, south of the former town. The property belongs to Mr. Asa Williamson, and consists of a series of small sulphur springs.

About a mile east of the springs, the brown hematite, which usually accompanies the siliceous shale, is seen in many places in that rock in a series of strata, from a few inches to several feet in thickness, alternating with similar strata of rock. Numerous such exposures occur on the western end of a ridge northeast of Gillam Springs, and in one place a surface exposure between four and five feet in thickness was seen. Larger outcrops are said to have been found and prospected in this neighborhood. Sometimes the same stratum is represented in one place by iron ore and in another by rock, and such occurrences often repeat themselves for several hundred yards.

Hannah Mountain. (*Manganese and iron.*)—Hannah Mountain is in 4 S., 29 and 30 W., and is one of the most prominent ridges in the novaculite belt of the Cossatot River. It runs from north of Tall Peak Mountain on the east in a direction of few degrees north of west, to the Brushy Creek fork of the Cossatot River, a distance of over ten miles. In this distance it is broken in only one place, and that is where the main Cossatot River has cut a deep pass through it, south of Rhode Post-office. Elsewhere, there are low places in its summit and mountain trails frequently take advantage of these to wind their course across the country, but such sags represent simply indentations in the ridge, and the only complete break is the Cossatot pass. The summit of the mountain comes up to a long, sharp crest, in some places only a few feet wide, and follows an undu-

lating line, reaching its maximum height in the High Peak of Hannah.

This peak is some three miles east of the Cossatot River and the mean of two barometric measurements gives it a height of about a thousand feet above that stream. The height above the sea level is not known, but an approximation made from the elevations given on the U. S. Geological Survey maps of the country immediately to the north, places the summit of the mountain about two thousand feet above tide water. It is the highest peak measured by the Survey in the mountains of the Cossatot and Little Missouri Rivers, though others closely approach the same height, and it is not impossible that a few may be found still higher. Hannah Mountain east of the Cossatot River is known as East Hannah, and west of that stream, as West Hannah.

Taking the ridge as a whole, it represents an anticlinal axis, in many places overthrown and dipping to the north. Its central part consists mostly of gray novaculite and the slopes are composed of the associated shale.*

There are numerous exposures of manganese and iron ores, similar to those already described, along the course of the ridge. The manganese is in the gray novaculite and generally at or near the contact of that rock with the siliceous shale. Its outcrops follow along the mountain and vary in position with the contact of the rocks, at times rising to the summit, but more generally dropping down a short distance on the slope, usually on the south side. This ore-bearing stratum goes under the name of the Hannah "lode" in the eastern part of the mountain, and the Fawn "lode" in the western part. The iron ore sometimes occupies a position similar to the manganese, but it also occurs in the shale lower down the mountain side. Several openings have been made on both East and West Hannah, and the principal ones are here described:

(1) East Hannah Mountain; the High Peak. (Iron.)—

* A section through East Hannah Mountain and the next ridge to the north, known as Shadow Rock Mountain, is given in figure 24, on page 322.

The High Peak of Hannah is a part of the Hannah ridge about three miles east of the Cossatot River. On the south slope of the mountain, and probably about three hundred feet from the summit, is a deposit of brown iron ore in the gray novaculite. The deposit is three feet in the widest part and about two-thirds of it is composed of ore. It follows along the slope of the mountain for about ten feet, and beyond these limits becomes thin and is often represented only by a stain.

Two miles east of the High Peak of Hannah, on the same mountain, small seams and nests of manganese and iron ores occur in the gray novaculite.

(2) East Hannah Mountain; the William Allen claim. (Manganese.)—The William Allen claim is on the north side of East Hannah Mountain, near its base, about a mile and a half east of the Cossatot River. It is on what is known as the Condor "lode," which contains manganese ore in seams and pockets from a fraction of an inch to eight or ten inches in thickness, scattered through the novaculite. The latter size, however, is exceptional, and the largest mass seen measured three by six by ten inches. The ore is of both the crystalline and massive varieties, the former often showing a plumose structure. The massive variety is hard, and often in stalactitic and mammillary forms. The manganese is associated with a glossy, black iron ore.

(3) East Hannah Mountain; the west end. (Manganese and iron.)—On the western end of East Hannah Mountain, in the neighborhood of the Cossatot River, both manganese and iron are scattered in small quantities through a belt of novaculite varying from five to twenty feet in width. In some places the ore is iron and in others manganese; in still others both ores are mixed together in varying proportions. They occur in thin seams along lines of bedding or joint cracks, or as the cement of a brecciated novaculite; in places also they are in small nodules, and often form only a stain in the rock. The rocks dip uniformly to the north at angles of from 60° to 80°.

(4) West Hannah Mountain; the William Allen claim. (Manganese.)—This one of the William Allen claims on West

Hannah Mountain is a quarter of a mile west of the Cossatot River, on the north slope of the mountain, and on what is known as the Fawn "lode." The manganese is in the gray novaculite, near its contact with the shale. The ore impregnates the rock for a width of ten feet in small seams and pockets from a quarter of an inch to three inches in thickness, and is both massive and crystalline. The manganese is associated with small quantities of brown iron ore.

Outcrops similar to this one are seen at intervals along the same slope of the mountain, associated with the same rocks, for a distance of some four miles, to the Brushy Fork of the Cossatot River.

(5) West Hannah Mountain; the Bowen claim. (Manganese.)—The Bowen claim is on the summit of West Hannah Mountain, at its extreme west end, four miles west of the Cossatot River, and overlooks the valley of Brushy Fork. Manganese is found here in the crystalline form with smaller quantities of a hard massive ore. It occurs in thin discontinuous seams occupying cracks and joints in the novaculite and sometimes forming the cement of a breccia. The largest mass of solid ore visible is three inches in thickness and three feet in length, thinning out at both ends.

Similar deposits occur along the summit of the mountain for half a mile east of the Bowen claim, and are separated by areas of barren rock. Occasionally brown iron ore instead of manganese, is seen in small quantities along the ore-bearing stratum, and sometimes both ores occur together.

Buckeye and Shadow Rock Mountains. (*Manganese and iron.*)—Buckeye and Shadow Rock are names given to different parts of a novaculite ridge which runs parallel to, and immediately north of East Hannah Mountain in 4 S., 28 and 29 W. In its eastern part it is known as Buckeye Mountain until within about four or five miles of the Cossatot River, and from that on to the river it is known as Shadow Rock Mountain. The ridge rises from five to eight hundred feet above the Cossatot, its average height being much lower than that of East Hannah to the south. It is separated from the latter ridge by

a deep ravine which marks the course of Short Creek, a tributary of the Cossatot.

A large number of claims have been taken on exposures of manganese and iron on both ends of the mountain, and the principal ones are here described:

(1) Manganese Mountain.—Manganese Mountain is a small spur of Buckeye Mountain, running out from the south side of the ridge about five miles east of the Cossatot River. Manganese is found here in the gray novaculite in the form of a hard, massive, steel-blue ore, blending at times into a semi-crystalline ore. It is generally in the form of flat, botryoidal or concretionary masses, often having hollow interiors. It tends to follow lines of bedding, but it also runs off in joint cracks. The bedded layers are the larger, and one of them measured from three to six inches in thickness and four feet in length. The seams in the joint cracks rarely measure over a quarter of an inch in thickness, though they are often so numerous as to honeycomb the rock in all directions.

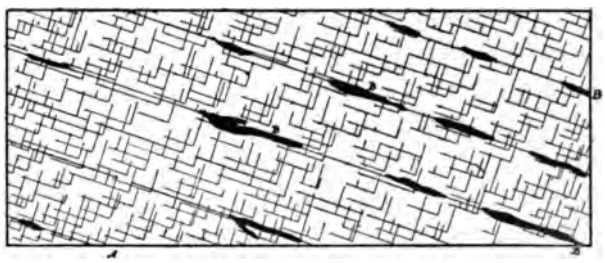

Figure 28. *Section in a pit on Manganese Mountain, Polk county, showing the occurrence of manganese ore in the gray novaculite.*

A. Gray novaculite.

B. Manganese ore.

Horizontal and vertical scale: 1 inch—3 feet.

The accompanying figure shows the character of the bedded deposits in the side of a small opening on the summit of the spur. It will be observed in the figure that the lenticular layers of ore lie intermittently along different planes of stratification, and that they are separated along the same planes by barren areas, which, however, are generally stained with iron or manganese. Sometimes the layers of ore are simply flat concretions.

The following analysis shows the composition of the ore from this locality:

Analysis of manganese ore from Manganese Mountain, Polk county.

Manganese	42.75
Iron	2.72
Silica	10.46
Phosphorus	0.45
Manganese peroxide	62.75

(2) The Walston claim. (Iron.)—The Walston claim is on the same hill as the last named locality and a quarter of a mile northwest of it. Layers from two to six inches in thickness of glossy black or dark brown iron ore are interbedded in the gray novaculite. The ore also runs across the stratification in fractures in the rock. The deposit occurs at the crest of a small, local anticline, and the layers of ore dip off in both sides of the pit. No manganese was seen at this opening.

Another one of the Walston claims is near the last and at the point where Manganese Mountain joins the main Buckeye Mountain. Iron ore similar to that just mentioned has been found here in a small pit now mostly filled up. It is said to have been in larger quantities than at the last place.

(3) Other localities on Buckeye and Shadow Rock Mountains.—A short distance west of the last locality, on the main Buckeye Mountain, and four miles east of the Cossatot River, are several other claims. A stain and occasionally a few small seams of iron and manganese ores occur in the rock, but no large deposit has been found.

Two miles east of the Cossatot River and on the south slope of the ridge, small masses of manganese and iron ores are scattered through the loose rock. The mountain here is known as Shadow Rock.

Two hundred yards farther down the slope of the mountain strata of brown hematite occur in the siliceous

shale. There are fifteen feet of interbedded layers of hematite and rock, with an undulating dip of 60° to 80° north and a strike in an east and west direction, parallel to the ridge. Sometimes the iron ore composes the larger part of the deposit, but usually the latter is rock stained with iron, thus giving the impression that the ore is more plentiful than it really is.

About a mile east of the Cossatot River, and still on the north slope of the mountain, several outcrops of manganese and iron ore occur in the gray novaculite, at or near its contact with the siliceous shale. This ore-bearing stratum is known locally as the Prince Edward "lode," a name which is somewhat indefinitely applied to almost all the claims on this ridge, from Manganese Mountain on the east to the Cossatot River on the west. The ore is composed of varying proportions of massive and crystalline varieties, the one running into the other. The iron ore is sometimes associated with manganese, sometimes free from it. Both ores run irregularly through a stratum of novaculite varying from three to five feet in width, and form from a tenth to a half the mass.

C. C. Avant claims. (*Manganese and iron.*)—Mr. Avant owns several claims in the vicinity of the upper waters of the Cossatot River, and two of them are here described:

(1) Manganese.—This claim is in 4 S., 29 W., section 6, on a novaculite ridge running parallel to, and north of West Hannah Mountain. The ore-bearing stratum is known here as the Eldridge "lode," and the Avant claim is near its eastern end, a few hundred yards west of where the ridge slopes off to the valley of the Cossatot River. Manganese ore is found in the gray novaculite on and near the summit of the mountain, and is of a hard, steel-blue variety, often in stalactitic and mammillary forms. The ore-bearing part of the rock varies from one to five feet in thickness and contains the ore in thin seams, from a fraction of an inch to eight inches in thickness, following the stratification or occupying joints and cracks. The ore-bearing deposit dips to the north

with the enclosing rock at angles from 70° to 90°, and is traceable for several hundred yards along the mountain, when it thins out, widening again to the west.

(2) Iron.—This claim is in 4 S., 30 W., section 1, about a mile west of the last locality (claim 1), on the south slope of the same mountain, and about a quarter of the way from the summit. Here the ore-bearing stratum is represented mostly by iron ore, though small quantities of a black, massive manganese ore sometimes occur. The iron ore is in the form of a brown hematite, and forms the cement of a brecciated novaculite, in which the rock masses vary from a fraction of an inch to six inches in diameter, and are sometimes stained throughout by iron. This mixture of rock and ore has a width of about thirty feet on the slope of the mountain, but only a small part of it is composed of ore.

The Arkansas Development Company's mine. (Manganese.)—The Arkansas Development Company's mine is in 3 S., 30 W., section 27, and is locally known as the Ward manganese mine, * from the name of the former superintendent. It is near the head waters of the Brushy Fork branch of the Cossatot River, on a novaculite ridge which rises over 400 feet above the creek. It is the property of the Arkansas Development Company, and was worked during the year 1888 and until April, 1889, when operations were stopped. During this time a shaft 142 feet deep was sunk on the north slope of the ridge, and a tunnel about500 feet long was run into the northern side, near the level of Brushy Fork. About twenty tons of ore are said to have been taken from the shaft; none was found in the tunnel.

The summit and upper slopes of the ridge are composed of gray novaculite, while on the north side, where the tunnel has been run, the lower slopes are composed of black siliceous shale. The manganese occurs in the novaculite in the form of crystalline pyrolusite, associated with a hard iron-gray massive ore, the former often coating the latter as an

* This property has been described by T. B. Comstock, Vol. I. of the annual report of the Geological Survey for 1888, pp. 155-157.

incrustation, and both occurring in kidney-shaped or stalactitic forms. Sometimes small quantities of a black iron ore (limonite) showing a glossy, brilliantly iridescent surface, are associated with the manganese, but a large part of the latter is free from such impurity.

The manganse-bearing deposit varies from one to two feet in thickness and dips almost vertically. The ore, however, composes only a small part of this and usually occurs as thin seams and pockets from a fraction of an inch to over two inches in thickness, scattered irregularly through the rock. Occasionally, however, the ore widens out locally into pockets of somewhat larger size. Sometimes the ore disappears altogether or is represented only by a stain in the rock, but widens out again at irregular intervals.

*Other openings made by the Arkansas Development Company on Brushy Fork.**—Several other smaller openings have been made by the Arkansas Development Company, on both manganese and iron, in the same neighborhood as the Ward mine. The most important are given below:

(1) The Jumbo pit. (Manganese.)—The Jumbo pit is five hundred yards east of the Ward mine, on the north slope of the same ridge. Manganese ore impregnates the novaculite in the same way as at that place. A pit fifteen feet deep and eight feet square has been sunk, and on all sides of it are seen thin, irregular, and discontinuous "stringers" of ore, from one to five inches in thickness, either in lines of bedding, or in joint cracks. The novaculite is generally stained a buff or a brown color, and is soft, often disintegrating into a powder.

(2) Tunnel No. 2. (Iron.)—Tunnel No. 2 is little over half a mile east-northeast of the Ward mine. It is twenty feet long and was run into a gray siliceous shale, on a deposit of brown iron ore. The ore is a brown hematite, interbedded in the rock in irregular pockets, from a few

* Several properties owned by this company elsewhere in Polk county have already been described. See pages 358-360.

inches to a foot or more in thickness. The ore is laminated and has much the same structure as the enclosing shale, into which it blends both laterally and vertically. The quantity of ore is very limited.

Two hundred yards northeast of this tunnel, is a small pit on a similar ore in a similar rock. The ore frequently forms the cement of a breccia of fragments of the enclosing rock, and is irregularly scattered through a stratum three feet thick. The shale in contact with the ore is often much decomposed and exists in the form of a fine, siliceous powder.

(3) Shaft No. 3. (Manganese.)—Shaft No. 3 is over a half mile northeast from the Ward mine, and is a pit eight feet square and twenty feet deep, sunk for manganese in the gray novaculite. The ore occurs in small nests and thin discontinuous seams, from one to six inches in thickness. Sometimes they follow joints, but the largest seams are in the bedding planes of the rock, which pitches to the southwest with an undulating dip of about 30°. The deposits in the joint cracks frequently cross those in the lines of bedding, showing that the ore in the bedding planes was deposited previously to that in the joints.

(4) Shaft No. 4. (Manganese.)—Shaft No. 4 is near shaft No. 3, is about the same size, and has been sunk in the novaculite for manganese. The ore is a hard, massive variety in a mammillary form, and occurs as in shaft No. 3, in lines of bedding and in joint cracks. The largest seam measured was four inches thick and four feet long, representing a lenticular layer.

Cossatot Mountain. (*Manganese.*)—Cossatot Mountain lies directly north of McKinley Mountain, already described, and is separated from it by Mine Creek. It is a novaculite ridge like McKinley Mountain and the many others already described. The portion of it referred to here runs through the southeastern part of township 3 S., 29 W., in a general west-northwest direction. To the east of this area, it bears off towards the Little Missouri River; to the west, it coalesces with the mountains south of Dallas.

Two and a half miles east of the Cossatot River, several small pits have been sunk for manganese on the summit of the mountain, and a tunnel forty feet long has been run into the north side about twenty-feet below the summit. The gray novaculite forms the crest of the ridge and the siliceous shale comprises the slopes. The tunnel has reached the novaculite through the shale. The manganese is in the form of a crystalline pyrolusite, mixed with a hard, massive ore, and occurs in irregular nests, from a quarter of an inch to three inches in diameter, and in thin seams, from a sixteenth to a quarter inch in thickness. Such bodies of ore are scattered irregularly through a breadth of about forty feet of novaculite. The manganese forms but a small portion of the ore-bearing stratum, and, except in the richest places, the aggregate amount of the scattered bodies of ore would form a very small percentage of the mass.

Little Manganese Mountain. (*Manganese and iron.*) — Little Manganese Mountain is the name given to the western end of the novaculite ridge running parallel to, and a mile south of East Hannah Mountain. Iron and manganese are found on it a mile east of the Cossatot River, where the mountain begins to slope down to the valley of that stream. The claim is owned by Mr. William Allen, and is known as the Cave "lode." The ridge here is composed mostly of gray novaculite, dipping at angles of from 45° to 60° north and overlain on the northern slope by the siliceous shale. In the novaculite near the contact with the shale, are discontinuous strata of brown hematite, associated with smaller quantities of manganese, and varying from a fraction of an inch to four inches in thickness. They run sometimes continuously in the direction of the ridge for fifty or sixty feet, and then thin out, appearing again beyond. The manganese is in much smaller quantities than the iron ore, and occurs in nodules and thin seams. As a rule, the iron ore seems to be largely confined to the contact of the novaculite and shale, while the manganese is found not only there, but also in the novaculite, farther from the contact line.

CHAPTER XIV.

THE MANGANESE DEPOSITS OF THE APPALACHIAN REGION.

LOCATION OF THE DEPOSITS.

Geographic position.—Manganese ores are of frequent occurrence throughout the region of the Appalachian Mountains from Maine to Alabama, but it is only locally that they have been found in workable quantities. Virginia, Georgia, and to a lesser degree Vermont, represent the only states * in that region in which any considerable quantities of the ore have been mined. †

The most important manganese area in the Appalachian region lies between the Potomac River on the north, and the head waters of the Alabama River on the south. These limits include the well known manganese districts of the Valley of Virginia and of northern Georgia, besides many other less known localities, not only in those states, but also in Maryland, West Virginia, Tennessee, North and South Carolina, and Alabama.

Topographic position.—The general surface features of the manganese-producing states in the Appalachian region are so well known that a detailed description of them here is unnecessary. A few words, however, are required to explain their relation to the subject in question. The mountains run in a general north-

* In addition to the deposits of these states, mention should be made of the manganiferous zinc ores of Sterling Hill and Franklin, New Jersey. These are used as a source of spiegeleisen after the zinc has been abstracted. The manganese, however, is a by-product, and the ores are mined primarily for their zinc. They have been described on pages 91-93.

† The manganese deposits of New Brunswick and Nova Scotia properly belong to those of the Appalachian region, but as they differ considerably from most of the Appalachian deposits they are treated in a separate chapter.

east and southwest direction, parallel to the Atlantic coast, in some places reaching the immediate shore line as in New England, in others receding from a hundred to two hundred miles from it, as along the coast of the southern states. The intervening space in the latter region is occupied by a comparatively low area, which slopes off gradually and becomes more and more nearly level until the flat tide water region is reached.

The mountainous area varies from less than a hundred to over two hundred miles in width, and is bounded on the west by the plateau area comprising the eastern part of the Mississippi basin. The mountains consist of a series of parallel ranges separated by intervening valleys, and follow the general northeast and southwest structure of the region. The most easterly of these ranges forms the Blue Ridge of Virginia with its southwesterly prolongation thence into Georgia and Alabama. To the west, are the Allegheny Mountains with their southwesterly extension in the Cumberland Range. Both the Blue Ridge and Allegheny Mountains with their southerly prolongations, include many minor and parallel ranges, such as the Black, Great Smoky, Unaka, Cheat, Clinch, and numerous other mountains. Between the two main chains is the Valley of Virginia, frequently divided longitudinally by subordinate mountain ranges, and continued on the north by the Cumberland Valley of Pennsylvania and the Lake Champlain basin of Vermont, and extending south into Tennessee and Georgia. This valley and its Blue Ridge barrier on the east have been the seat of nearly all the manganese mining in the Appalachian region, though, as will be shown in the next chapter, work has also been done elsewhere both to the east and the west.

HISTORY OF MANGANESE MINING IN THE APPALACHIAN REGION.

The general historical features of manganese mining in America, in which the Appalachian region has, so far, played the most important part, have been given in chapter IV. Only a summary of the general facts which pertain to this special area need be repeated here, while minor details concerning individual properties are given under the descriptions of those places.

The first manganese mining in the United States, so far as it is possible to find out, was done near Whitfield, in Hickman county, Tennessee, where small quantities of ore were taken out in 1837. Similar amounts have been mined since then at the same place for use in coloring pottery. * In 1859, Mr. Sibert made several small openings in the manganese deposits of the Valley of Virginia, at the Lyndhurst mine, the Kennedy mine, and elsewhere, and is said to have shipped some ore. Manganese is said to have been mined at the Van Buren and Paddy Mills mines in Virginia at nearly the same time or shortly afterwards, but in small quantities. About the same time also manganese mining was carried on in Vermont. The exact year that work was begun in this state is uncertain, but it is stated † that, in 1861, considerable quantities of manganese ore had already been shipped to England from Brandon and Chittenden.

In 1867 Mr. James E. Mills commenced a thorough examination of all the manganese deposits of the Appalachian region so far as then known, and shortly afterwards he opened the Cabell mine in the Valley of the James River. His work represented the first serious attempt to mine manganese systematically and on a large scale in this region.

In 1867, the Crimora mine in the Shenandoah Valley, in the same state, was bought by a stock company which suspended operations in 1869. From that time until 1882 the mine was worked intermittently, but only small quantities of ore were shipped. In 1867, the Dobbins mine near Cartersville, Georgia, was opened and was the first manganese property worked in that state.

During the next ten years (1867-1877) the manganese industry grew steadily but slowly in both Virginia and Georgia, but in the other states represented in the region, very little was done, though in North Carolina small quantities of ore were mined. Up to this time most of the ore mined had been sent to

* Joseph D. Weeks, Mineral Resources of the United States, 1885, p. 345.

† Geology of Vermont, E. Hitchcock, E. Hitchcock, jr., A. D. Hager, and C. H. Hitchcock, 1861.

Europe and was principally used for chemical purposes; but the rapidly growing manufacture of Bessemer steel in the United States greatly increased the demand for manganese, so that in the next decade several companies, producing considerable quantities of ore, came into existence; and from 1880 to 1890 their number and output steadily increased. In 1882 the Crimora mine was leased by James B. White and Company, and is now operated by the American Manganese Company. It has been the largest producer of manganese in the United States, and up to December 31, 1888, its total output was about 103,785 tons of ore.* Smaller quantities have been produced at many properties both in Virginia and Georgia, as is shown in the following chapter, though with the exception of limited operations in western North Carolina, but little work has been done in the intervening states. Statistics of production in the Appalachian region are given in chapter IV., pages 65–68, and also in the descriptions of individual localities in chapter XV.

In conclusion it may be said that, though manganese has been mined in many different places in the last twenty years in the part of the Appalachian Mountains lying between the Potomac and the Alabama Rivers, only a few of the mines have proved to be profitable. In fact the areas of important mining have been almost entirely confined to Virginia and to the Cartersville region of Georgia; while even in these regions they are still farther narrowed down to the Crimora mine and a few others in Virginia, and to a few localities in Georgia. At other places manganese has been mined at a profit for short intervals, but most such localities have not stood the test of time. Three causes have combined to bring about this result:

(1) Many of the deposits worked were far from railways, and the expenses of transportation consumed the profits.

(2) Ignorance on the part of the operators of the nature and mode of occurence of the ore has hastened the downfall of many properties. This was especially true in former times when the character of manganese deposits was not so well understood

* Mineral Resources of the United States, 1888, p. 133.

as it is now, and many errors were committed that would not be made by the more experienced manganese miner of to-day.

(3) The irregular mode of occurrence of the ore has caused the failure of many mines: the aggregate amount of manganese in the region is large, but it is only occasionally that enough of it occurs in one place to permit it to be profitably worked. Manganiferous iron ores have been found in considerable quantities in many places, but manganese ore proper is much less abundant and more uncertain.

In spite of this irregularity in the mode of occurrence of the ore, however, the Appalachian region ranks today as one of the leading manganese-producing areas of the world. Moreover, the large production of the Crimora mine, and the smaller yet considerable production of other mines in Virginia and Georgia, prove that extensive deposits of manganese ore can be found in the Appalachian region, and leads to the belief that other large deposits may be discovered in the same geologic relations; while the gradually increasing railway facilities may be expected to add largely to the number of paying mines, not only in Virginia and Georgia, but also in other states in the region.

THE GEOLOGIC RELATIONS OF THE MANGANESE DEPOSITS.

The manganese ores of the Appalachian region occur in rocks of several geologic horizons from Archean to Tertiary. In fact manganese in greater or less quantities characterizes many of the iron ore belts throughout this area, but the only deposits that have been worked to any considerable extent as a source of manganese are in the Cambrian and Silurian rocks. Even in these rocks the more important localities are, in some places at least, still farther narrowed down to the areas of Cambrian quartzite and the immediately overlying limestones or shales.

Speaking geographically, the main manganese-bearing stratum, which in different places may be represented by either manganese or iron or both, skirts the western and northwestern slopes of the pre-Paleozoic crystalline rocks, and passes through the Ap-

palachian Valley from northern Vermont to Alabama. It runs along the eastern side of the Lake Champlain basin, through the Cumberland Valley of Pennsylvania, the Valley of Virginia and of East Tennessee, the western parts of North and South Carolina, the northern part of Georgia, and into Alabama, where it finally disappears under the Cretaceous and Tertiary strata of the Lower Mississippi Valley.

In this belt of country, the most prominent manganese deposits occur in a residual clay in or overlying quartzite. Whether these deposits occupy the same horizon throughout the Appalachian Valley, or whether they represent two or more different horizons is a matter as yet of some uncertainty. To the west of the area of the deposits associated with quartzite, manganese is found in several horizons in the Upper Silurian rocks, but the belt of deposits here referred to includes those of Brandon and South Wallingford in Vermont; Crimora and Lyndhurst (Augusta county), the Cabell mine (Campbell county), and other places in Virginia; Holston Mountain in East Tennessee; and the Cartersville region in Georgia. These localities are in areas that have heretofore been designated as Cambrian sandstone, mostly Potsdam.

The late investigations of the United States Geological Survey, however, though they have corroborated the Cambrian age of many of these sandstones or quartzites, have shown that in the case of others, there is evidence that they belong to a later horizon, and in some cases to the Upper Silurian. The evidence at present seems to point to the existence of three great quartzite formations in the Appalachian belt*: the first and lowermost is of Lower Cambrian age and represents the Granular quartzite of the western slope of the Green Mountains; the second is of Upper Cambrian age and represents the Potsdam sandstone; the third represents the Medina horizon of the Upper Silurian. The first and third of these formations have been found abutting against the western slope of the crystalline rocks in the Appalachian region, and represent deposits occupy-

* The Survey is indebted to the kindness of Mr. Charles D. Walcott, Paleontologist of the United States Geological Survey, for the facts in this classification of the quartzites.

ing successively higher positions on the edge of these rocks, which once formed the more or less steeply sloping border of the Paleozoic sea. The quartzites often resemble each other in many respects, having derived the sediments of which they are composed largely from the same type of crystalline rocks. As the quartzites are all, at times, found in contact with the crystalline rocks, this position cannot always be taken as an indication of their age. Consequently it is frequently impossible to decide, without the aid of paleontology, to which of the three horizons the quartzite in any one place may belong.

As shown in the description of South Wallingford, Vermont, in the next chapter, the manganese ores of that locality occur between quartzite and limestone, which are probably of Lower Cambrian age. This probability has been shown by the late investigations of Dr. J. E. Wolff, of the United States Geological Survey, who has proved the Cambrian age of what appears to be the same limestone a few miles north of South Wallingford. (See South Wallingford.)

In Virginia, Mr. Bailey Willis, of the United States Geological Survey, and his assistants, have determined certain quartzites near Harper's Ferry as of post-Trenton age; while the quartzites of the Cartersville region, Georgia, according to information kindly furnished the Survey by Dr. C. W. Hayes, of the United States Geological Survey, are of as yet uncertain age, and may belong in the Cambrian or in the Upper Silurian. On the other hand, elsewhere in Virginia, Tennessee, and other states throughout the Appalachian belt, undoubted Cambrian quartzites occur in numerous localities.

There is as yet, therefore, some doubt about the relative ages of those manganese deposits in the Appalachians which are associated with quartzites. Some have been proved to be of Cambrian age, others are undetermined, but have not yet been proved to be other than Cambrian.

The mode of occurrence of the ores, especially from Vermont to Tennessee, is remarkably alike: They occur at or near the contact of quartzite and overlying limestones and shales, sometimes directly on the line of parting, at other times in the

upper part of the quartzite, or the lower part of the limestones or shales. Manganese, like iron, however, is of very general distribution in various geologic horizons, and it is as yet premature to attempt to state the exact relation of all the manganese deposits in the quartzite area of the Appalachian Valley. The stratigraphic and lithologic similarity of the deposits in this district requires the further support of paleontologic evidence, before the relations of the different localities can be determined. The evidence at present available, however, in the region from northern Vermont at least as far south as Tennessee, seems to suggest the possible Cambrian age for many, if not most of those manganese deposits in or immediately above the quartzite.

Besides the deposits in the Cambrian or Silurian quartzite or the associated strata, manganese ore also occurs in both older and younger formations. The other deposits, however, have produced only limited quantities of ore, and but few of them are being worked at present.

The ores in the Archean and other pre-Paleozoic rocks forming the eastern and southeastern parts of the Appalachian Mountains, are mostly in the forms of rhodonite and other silicates, in which conditions, on account of their high percentages of silica, they are not available, according to present standards, as sources of manganese. Rhodochrosite, or carbonate of manganese, is sometimes associated with the silicates, but it is in too small quantities to be of economic value. It has probably in some cases resulted from the alteration of the silicate. Generally the outcrops of the deposits of manganese silicates have been partially decomposed and various oxides of manganese have been formed, but this alteration is usually only superficial. (See page 85.) Wad is also of frequent occurrence in the area of crystalline rocks and has resulted mostly from the decomposition of the silicates of manganese, and to a lesser degree from that of other manganese minerals.

The ores in the crystalline rocks, together with their alteration products as just described, comprise almost all the manganese of Maine, New Hampshire, and Massachusetts, as well

as of certain other localities in the Appalachains, and are further described under the different states.

Manganese ores belonging in Upper Silurian limestone are said to be found in the mountains west of the Valley of Virginia. In Georgia the principal manganese region is in the quartzite area north and northeast of Cartersville (see next chapter); but there is another area in Floyd and Polk counties south of Cave Spring, about thirty miles west of the Cartersville region, where the manganese occurs in chert or cherty limestones which represent Lower Silurian rocks. These rocks according to C. W. Hayes correspond to the Knox dolomite of Safford.* The same conclusion has also been reached by Dr. J. W. Spencer, State Geologist of Georgia. Similar ores occur north of Cave Spring in the neighborhood of Tunnel Hill in Whitfield county, and elsewhere in the same part of the state. Carbonate of manganese often forms a small proportion of the carbonate, or spathic iron ores in Silurian and Devonian shales and slates, in various parts of the Appalachian region.

Manganese in small quantities in the form of carbonate is characteristic of the spathic iron ores in the Carboniferous rocks of Pennsylvania and elsewhere. It forms, however, only an unimportant part of the ore,from a fraction of a per cent to 4.5 per cent of carbonate of manganese (equal to 2.12 per cent of metallic manganese). †

Manganese ores are said to have been found in the Tertiary sediments in the coastal area of Virginia, and to have been mined near City Point on the James River.

THE MANGANESE ORES.

Mineralogical forms of the ores.—The workable manganese ores in the states in question are mostly massive psilomelane and crystalline pyrolusite, ‡ though manganite ‖ probably also

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* See description of the manganese deposits of Georgia in chapter XV. of this report.

† H. D. Rogers, Geology of Penn., 1858, Vol. II., p. 739. Andrew S. McCreath, Chemical Analyses, Second Geol. Survey of Penn., 1879, Vol. M. M., pp. 159-184.

‡ A detailed analysis of pyrolusite from the Crimora mine, Virginia, is given on page 97.

‖ A mineral that is probably manganite is described under the discussion of the manganese deposit of South Wallingford, Vermont, in the next chapter.

occurs, and it is possible that a careful search might reveal the presence of braunite * and perhaps hausmannite.

Wad sometimes occurs, as well as rhodonite and other manganese-bearing silicates, but such minerals are not at present available as manganese ores. † Rhodochrosite, or carbonate of manganese, occurs in many places, though it has not yet been found in commercially important deposits anywhere in the United States. All the above mentioned minerals have been described in chapter V., and do not require further mention here. As stated in that chapter the different varieties of oxides of manganese are intimately associated with each other, and blend together without any sharp line of separation. It is the exception that pure masses of any one oxide are found. The most striking physical differences in the ores are their massive or crystalline characteristics; but a sample of crystalline ore may include two or more crystalline oxides, and a sample of massive ore may include two or more varieties of massive oxides. The exact nature of the ore, therefore, in many cases must be determined by chemical analysis. Time has not permitted a detailed examination of the chemical nature of all the manganese oxides collected in the Appalachian region, and therefore in the descriptions of localities given in the next chapter, whenever there is any doubt about the mineralogical nature of the ores, they are simply referred to as massive or crystalline, as the case may be. The manganese ores are frequently associated with iron ore in the form of more or less manganiferous brown hematites, as explained below and also on pages 87-89.

Commercial value of the ores.—So far as the analyses at hand

* The name braunite is most indiscriminately applied to manganese ores in the Appalachian region and even elsewhere, under the delusion that it necessarily refers to an ore of a brown color. The name was not given on account of the color of the mineral, but was applied by Wm. Haidinger (Edinburgh Jour. Sci., 1826, Vol. IV., p. 48) in honor of Mr. Braun of Gotha. As a matter of fact the mineral braunite, though sometimes of a brown color, is very often, if not generally of a black color, and the relation of the name to the color of some specimens is purely accidental. As a result of this wrong idea of the name, a mistake commonly made is to include as braunite those manganese ores which contain more or less iron and are thereby subject to a brown or rusty discoloration. The only region in the United States where braunite has been proved to occur in quantities is in the Batesville region of Arkansas (see pages 148-154).

† See chapter V.

show, the ores in large shipments average* from 40 to over 50 per cent of manganese, from less than 1 per cent to over 15 per cent of silica, and from less than 0.10 per cent to over 0.5 per cent of phosphorus. The amount of silica and phosphorus is so variable that a statement of an average is of but little value, and frequently the limits given above are exceeded. The amount of peroxide of manganese that could be used for chemical purposes is also very variable. As pyrolusite contains a larger amount of this material than any other ore of manganese, being when pure composed entirely of it, the amount of peroxide depends largely on the quantity of pyrolusite present in the ore. This subject has been more fully explained in chapter III., pages 40-42.

In the amount of iron present, the range of variation is even greater than in other ingredients, and may be said to run all the way from less than one per cent upwards until the manganese ore merges into a manganiferous iron ore, in which the iron replaces the larger part of the manganese. There are still further stages where the iron completely replaces the manganese. Between the two extremes of pure manganese ore and pure iron ore, there is every imaginable gradation in the amount of admixture of the two materials. The iron ore associated with the manganese is usually a brown hematite and the admixture occurs in a great number of ways: sometimes it is an intimate and apparently homogeneous combination, which has the appearance of a manganese ore when iron is in small quantities, and of an ordinary brown hematite when manganese is in small quantities. At other times, the manganese is covered with a rusty stain of iron, or occurs as crystals lining cavities in the hematite. Frequently masses of hematite are coated by a crust of manganese ore, and often the two ores occur in alternating layers with well defined lines of separation between them. In such cases, the iron ore always largely predominates, the manganese being only a subordinate feature of the bed. The latter

* These statements of average percentages refer only to the oxide ores of manganese, and not to the silicates, which are much lower in manganese and higher in silica than the oxides. The silicates are not used as a source of manganese in this country. (See page 85.)

ore is also much more uncertain in its distribution than the iron, and the interbedded layers of it in hematite deposits are always lenticular, alternately running out and reappearing.* The manganese ore is not always, however, in such close association with the iron ore: in some places the two ores occur in distinct beds each containing comparatively little admixture of the other, and yet existing in the same neighborhood and enclosed in the same rock or clay.

By far the larger part of the manganese ore mined in the Appalachian region is at present used in the manufacture of spiegeleisen and ferro-manganese for admixture with steel. In former times it was mostly sent to Europe and consumed in chemical manufactures, especially in making chlorine for bleaching powders. At present also certain quantities are used in this country as a reagent in the manufacture of bromine, and of glass, and for other chemical purposes, but they are inconsiderable in comparison with the amount consumed in making Bessemer steel. (See chapter II.)

The following analyses with the exception of No. 24, which was made of a cargo of 186 tons sent to England, all represent the composition of car-load shipments of manganese ores from different states in the Appalachian region.

Analyses 1-10, 20-23, and 25-32 were kindly furnished the Survey by Mr. H. M. Curry, of the firm of Carnegie Brothers and Company, Pittsburg, Pa.

Analyses 11-19 were kindly furnished the Survey by Mr. John Fulton, General Manager of the Cambria Iron Company, Johnstown, Pa.

Analysis 24 is quoted from Mr. James E. Mills, American Chemist, August, 1871, page 51.

* For further details concerning manganiferous iron ores see pages 87-89.

Analyses of car-load shipments of manganese ores from the Appalachian region.

No.	LOCALITY.	Manganese.	Iron.	Silica.	Phosphorus.	Moisture.	Quantity sampled.	Analyzed by
1	Vermont.....	20.37	31.65	12.77	0.125	5.00	1 car or more	Carnegie Bros & Co.
2	" " "	19.71	29.27	14.00	0.145	8.00	" "	" " "
3	Virginia.....	43.38	9.63	9.75	0.068	4.00	" "	" " "
4	" " "	43.61	6.65	10.48	0.221	1.50	" "	" " "
5	" "	42.95	14.85	3.60	0.184	6.00	" "	" " "
6	" " "	37.69	12.37	10.60	0.153	9.00	" "	" " "
7	" " "	28.31	27.83	4.46	0.067	4.00	" "	" " "
8	" " "	35.36	20.95	6.25	0.780	5.00	" "	" " "
9	" " "	36.03	8.70	16.38	0.113	7.00	" "	" " "
10	" " "	33.60	16.59	14.75	0.095	3.00	" "	" " "
11	" " "	42.47	10.43	7.65	0.131	6.80	1 car	Cambria Iron Co.
12	" " "	46.41	.....	.....	.....	.....	" "	" " "
13	" " "	36.33	.....	.....	.....	4.70	" "	" " "
14	" " "	39.99	13.01	.....	.....	7.10	" "	" " "
15	" " "	46.24	8.76	.....	.....	7.70	" "	" " "
16	" " "	40.05	6.87	19.51	0.109	4.40	" "	" " "
17	" " "	41.29	6.23	18.51	0.096	4.60	" "	" " "
18	" " "	42.27	11.43	7.50	0.122	5.80	" "	" " "
19	" " "	41.50	10.56	9.77	0.108	.....	5 cars	" " "
20	Va. (Crimora).....	49.16	1.75	9.80	.....	6.00	1 car or more	Carnegie Bros & Co.
21	" " "	48.53	1.99	10.20	0.103	3.00	" "	" " "
22	" " "	50.54	1.96	10.12	.....	3.00	" "	" " "
23	" " "	48.16	4.57	10.30	0.095	3.00	" "	" " "
24	Va.(Cabell mine)*	44.78	4.34	14.20	0.180	.....	(cargo of 186 tons)	John Pattinson.
25	South Carolina....	45.02	2.75	8.10	0.085	9.00	1 car or more	Carnegie Bros & Co.
26	Georgia.....	41.25	9.10	14.40	0.109	2.00	" "	" " "
27	" " "	41.63	1.99	10.82	0.050	4.00	" "	" " "
28	" " "	42.86	10.49	7.30	0.139	6.00	" "	" " "
29	" " "	44.31	4.60	10.95	0.156	6.00	" "	" " "
30	" " "	34.16	13.59	12.90	0.167	8.00	" "	" " "
31	" " "	36.18	7.08	16.40	0.053	1.00	" "	" " "
32	" " "	39.89	10.21	12.72	0.106	6.00	" "	" " "

* Only a part of the analysis is given here, and it is expressed in terms different from the original in order to suit the system of this table. The analysis is quoted in full under the description of the Cabell mine. The ore contains 65.20 per cent of peroxide of manganese.

MODE OF OCCURRENCE OF THE MANGANESE ORES.

Derivation of the ore deposits.—The manganese ores of the main quartzite belt of the Appalachian Mountains, described on pages 376–379, usually occur as irregular bodies imbedded in clay. Both the ore and the clay once formed a part of shaly, calcareous, or sandy rocks, either immediately over the quartzite or imbedded in it. Sometimes also the ore occurred alone in the quartzite, without the other strata.

The clay in which the ores are now found represents the residual product of the surface decay, in situ, of the original rock, and occupies the same or approximately the same position as that rock formerly held. It is bordered on either side by rocks which have undergone much less decay, and conforms to all the folding exhibited in these harder strata.* The clay deposits, on account of their softness, have suffered considerably more from erosion than the associated rocks, and now usually occupy hollows or basins in the mountains, such as are seen at Crimora, Lyndhurst, and elsewhere in the Valley of Virginia; and at the Chumler Hill and other mines in Georgia. Where the decayed rock covers considerable areas, however, erosion has often left one part higher than another, and in such cases the ore is sometimes found on low hills. Such an occurrence is seen at the Dobbins mine in Georgia.

Though the ore-bearing bed is usually in the form of residual clay, it has in some places retained its rock form even on the surface, and in such cases there is an opportunity to compare the position held by the ore in the original deposit with that in the decomposed bed. This examination leads to the belief that the ore as now found in the clay, is in a position very similar to that which it held in the solid rock, though it has sometimes been broken up in the disintegration of the bed, and has in some cases been influenced by minor chemical action.

The ore deposit is frequently derived from beds of more or

* Principles of derivation similar to those given here for manganese have been already described in the case of certain iron ores in the Appalachian Mountains by R. M. S. Jackson, J. P. Lesley, B. S. Lyman, T. Sterry Hunt, and Persifor Frazer, and are further discussed in the final chapter of this report.

less calcareous shale or schist, and often still preserves something of a shaly structure. In some places it has resulted from the decay of a fine grained, earthy, and often shaly sandstone, while away from the ore-bearing part of the bed the sandstone becomes coarser. When the ore-bearing stratum decays the earthy part forms clay and the coarse sandstone is the only rock seen on the surface. In other places the ore bed has been derived by the disintegration of a coarser sandstone, and in such cases the deposit is more or less sandy, varying in character and manner of admixture just as the original rock varied. Sometimes the manganese ore and the enclosing clay have come from the decomposition of thin, interbedded strata of limestone, shale, and sandstone which overlie the main sandstone or quartzite bed, and the character of the clay depends directly on the relative proportions of the different strata from which it was derived.

The color of the clay enclosing the ore depends directly on the chemical character of the original rock, though the action of oxidation during decay has often caused the clay to assume a color very different from that of the rock. The color of the clay varies considerably, being red, yellow, brown, purple, or black, and sometimes, though rarely, pure white. The black is especially noticeable near the ore bodies, and is probably due to the presence of finely disseminated oxide of manganese. Frequently the different colors occur together, giving the clay a brilliantly variegated appearance. All the colors are largely due to a stain of iron and manganese in different degrees of oxidation and hydration, hence producing a variety of colors.

Distribution of ore in the clay.—The manganese usually occurs in the form of nodules, pockets, or lenticular layers, often widening out into larger bodies and contracting again until another large pocket is met. In whatever form the ore is found, it seems to conform in a general way to the bedding of the enclosing material, though the disconnected character of the deposits sometimes renders this tendency obscure. At times, side pockets and "stringers" of ore extend from the main deposit and cut directly across the bedding, but these are probably due

to a secondary process of solution and re-deposition which took place after the formation of the bedded deposits.

The ore-bearing pockets vary greatly in size, from mere nests to bodies five or six feet in thickness and often twenty or thirty feet in length. They vary as much in number as they do in size, in some places being comparatively close together, in others fifty or a hundred feet apart. Their longer axes almost invariably run in the direction of the enclosing strata, and as these usually stand at high angles, the pockets generally have a steep dip. The pockets are composed either of comparatively solid ore, or of numerous nodules more or less closely assembled in the enclosing clay. The more solid deposits generally contain masses of clay or long lenses of the same material, dividing the bed longitudinally. Frequently the ore occurs in numerous thin seams honeycombing the bed in all directions and giving it a brecciated appearance; but even in such cases, the breccia as a whole follows certain fixed lines in the direction of the stratification of the rock.

The iron ore occurs in the clay in a manner somewhat similar to the manganese, but it is in deposits of much greater size, and is less discontinuous and uncertain in its extent.

Masses of the ore-bearing rock in the clay.—Associated with the manganese ore in the clay, are fragments of the original shale or sandstone varying from a few inches to five or six feet in diameter, and often containing masses of ore. They are in all stages of decomposition, from a solid massive rock to a soft, disintegrating material, the latter often coating the former. They represent more resistant, or else better protected parts of the original bed, which have thus far escaped decomposition.

The original rock was often a shaly material with lenticular masses of quartz and other hard rock; and when the bed decayed, the harder masses remained, while the enclosing material was completely converted to residual clay. Hence in many places the only rocks seen in the clay are these more resistant masses, and they are apt to give the false impression that they once formed the bulk of the bed, whereas they often comprised only a small portion of it. The loose masses of rock are

often in the shape of small angular fragments of quartz veins or of a breccia cemented by ore. The number of rocky fragments varies in different places, and probably depends largely on the nature of the rock of the original bed, the more resistant varieties leaving more fragments than the less resistant.

Extent of the ore-bearing clay.—The dimensions of the ore-bearing clay beds are uncertain, for the deposits are usually covered by soil and their extent is known only where they have been worked. They are probably, however, in some places several hundred feet thick, though the ore is not found everywhere in them, but is scattered through them in pockets, as already described. The rocks generally dip at steep angles, and the downward continuation of the ore-bearing stratum may therefore be looked for to an indefinite depth, with ore existing in it irregularly. At certain depths, the clay may be expected to merge into solid ore-bearing rock, but such depths are often considerable, and some of the deepest mines in the region are still working in clay. At the Crimora mine, a drill-boring showed clay still at 276 feet from the surface, but the deposit was not tested farther. At a depth, however, the clay at this mine becomes more compact and approaches its original shaly or massive structure.

The depth of the rock decay varies greatly and is directly dependent, other things being equal, on the character of the rock and the condition of disturbance of the strata. A more resistant rock will, of course, be decomposed to a less depth than one that succumbs more easily to decomposing agencies. A rock tilted at a high angle seems also often to decompose more rapidly, and to a greater depth in a given time than one inclined at a low angle, as, in the former case, the surface waters find easy access into the bed along the lines of stratification, while in the latter case the more gently inclined rocks tend to shed the water. Instances of this are seen in many places, especially in Tennessee and Georgia.

CHAPTER XV.

THE MANGANESE DEPOSITS OF THE APPALACHIAN REGION.—*Concluded.*

THE MANGANESE DEPOSITS OF MAINE, NEW HAMPSHIRE, MASSACHUSETTS, CONNECTICUT, AND RHODE ISLAND.

General features.—Manganese has been found in many places in the above mentioned states, but it is either in quantities too small or of quality too poor to be of value. It often occurs as rhodonite or rhodochrosite in interbedded layers in the crystalline rock. Another common form is wad, which has often been formed by the alteration of rhodonite and rhodochrosite. It is usually too low in manganese and too high in silica and other injurious impurities to be of value as an ore, though it has been mined for making paint. In some places the manganese occurs as an oxide of good quality, but so far as this has been found, it is in small quantities of no commercial importance.

Maine.—In Maine rhodonite and bog manganese, or wad, occur at Blue Hill on the Atlantic coast, and in other places in the state. At Blue Hill rhodonite is said to have been mined at one time for fluxing purposes at the Katahdin Iron Works, Bog manganese has been mined in Knox and Oxford counties. On Mt. Desert Island a deposit of a brilliant red, manganiferous ochre occurs on the road between Bar Harbor and Seal Harbor.

The following analyses show the composition of the Blue Hill ore:

*Analyses of manganese ore from Blue Hill, Maine.**

	(1)	(2)	(3)
Manganese protoxide...	35.13	29.72	15.00
Ferrous oxide.....	14.01	24.91	12.00
Alumina.....	7.45	3.04	.....
Lime.....	3.49	5.02	.....
Phosphoric acid.....	1.02	.....	.....
Silica.....	35.84	35.70	39.00
Manganese..	27.20	23.02	11.62
Iron.....	10.90	19.37	9.33
Phosphorus	0.45	.....	.....

No. 1 was analyzed by R. H. Rickard; No. 2 by the Scranton Steel Company; No. 3 by the Cambria Iron Company.

New Hampshire.—In New Hampshire, an impure rhodonite, with greater or less quantities of oxides, has been found at Winchester and Hinsdale.† Pyrolusite has also been found at Shelburne and other localities.

Massachusetts.—In the Berkshire Hills of Massachusetts, rhodonite associated with oxides of manganese has been found in many places. At Cummington the rhodonite is of a beautiful pink color and has been mined for ornamental purposes and for cutting into gems. Manganese also occurs at Plainfield,‡ Sheffield,§ Berkshire, Deerfield, Leverett, and on the east slope of Hoosac Mountain.‖ East of the Hudson River, in Massachusetts, manganese often exists in lenticular, interstratified masses, associated with carbonate of iron; elsewhere in western Massachusetts manganese in small quantities is a common accompanyment of iron ores.

Connecticut.—In Connecticut small quantities of manganese occur in several places in the western part of the state, at Redding, Salisbury, and elsewhere. It is frequently associated in small quantities with iron ores.

* Mineral Resources of the United States, 1885, p. 342.

† C. H. Hitchcock, Geol. of New Hampshire, Vol. I., 1877.

‡ Jacob Porter, Amer. Jour. Sci., 1st series, Vol. VII., 1824, p. 54.

§ Calvin Prescott, Amer. Jour. Sci., 1st series, Vol. IV., 1822, p. 189.

‖ E. Hitchcock, Amer. Jour. Sci., 1st series, Vol. XXII., 1832, p. 61.

Rhode Island.—In Rhode Island, manganese occurs near Sneech Pond.* It is also found in the form of oxide on the east side of Blackstone River, two and a half miles north of Pawtucket.†

The following analysis by Professor C. T. Jackson shows the composition of the Sneech Pond ore:

Analysis of manganese ore from near Sneech Pond, Rhode Island.‡

Manganese protoxide	32.8
Ferrous oxide	35.9
Silica	26.4
Carbonic acid	5.2
	100.3

Manganese	25.4
Iron	27.9

THE MANGANESE DEPOSITS OF VERMONT—*Location and general features.*

Manganese has been found in many places in the western half of the state of Vermont, and has been worked at several of them, especially near South Wallingford and Brandon in the Otter Creek valley, and at Chittenden and other places. The ore at the first two places occurs either at the contact of the Cambrian sandstone and the overlying limestone, as at South Wallingford; or, as at Brandon, in Tertiary beds which have probably been formed by the rearrangement of the materials from the same, or nearly the same horizon.

Otter Creek, which drains the valley of that name, rises in the southern part of Vermont, and flows north along the western slope of the Green Mountains, emptying into Lake Champlain about twenty miles south of Burlington. A large part of the valley, especially from Rutland northward, is cut through the limestone already mentioned, which represents the Eolian limestone of the Geology of Vermont.§ The exact geologic

* C. T. Jackson, Amer. Jour. Sci., 1st series, Vol. XL., 1841, p. 185.

† Samuel Robinson, Amer. Jour. Sci., 1st series, Vol. VIII., 1824, p. 231.

‡ C. T. Jackson, Amer. Jour. Sci., 1st series, Vol. XL., 1841, p. 185.

§ Geology of Vermont, E. Hitchcock, E. Hitchcock, jr., A. D. Hager, and C. H. Hitchcock, 1861.

horizon of this formation has been a matter of considerable dispute and it has been variously referred to horizons from Lower Cambrian to Chazy. The survey has been kindly informed, however, by Dr. J. E. Wolff, of Harvard University, that, in his work in that region for the United States Geological Survey, during the summer of 1890, he was enabled to determine with certainty a locality of this limestone, near Rutland and some ten miles north of the town of South Wallingford, as Lower Cambrian. It seems probable that the limestone at South Wallingford may represent the same horizon.

East of Otter Creek, and running parallel to it in a north and south direction, is a series of quartzite ridges, rising several hundred feet above the valley, and representing the western slopes of the Green Mountains. These rocks form a rugged barrier to the valley and their superior hardness over that of the limestone has doubtless largely influenced the course of Otter Creek. They belong below the limestone referred to and are, therefore, probably of Lower Cambrian age. To the east of the quartzite ridges is the main range of the Green Mountains, composed largely of metamorphic rocks. To the west of the Otter Creek valley, and forming the western border of Vermont, are the unaltered fossiliferous rocks representing Lower and Upper Silurian horizons.

Iron ore was mined in Vermont in the early part of this century, but the first work on manganese was considerably later. The two ores are often found together, but the manganese was, in early times, considered to be injurious to iron ore, and was avoided. The early shipments of manganese were mostly made to England, but the exact date is uncertain. They probably began, however, between 1850 and 1860, and, mostly likely, nearer the latter date.* No manganese is mined in the state at present (December, 1890), though work was done on the deposits of Brandon and South Wallingford in 1889, and was continued until the summer of 1890.

THE MANGANESE DEPOSITS OF VERMONT—*Otter Creek valley.*

The South Wallingford mine.—The village of South Wall-

* Further facts concerning the history of this region are given on pages 59 and 374.

ingford is on the Bennington and Rutland Railway, thirteen miles south of Rutland. Manganese and iron are found together about a quarter of a mile east of the railway, on the west slope of a quartzite ridge. The deposit was discovered about sixty years ago by Mr. Johnson, of South Wallingford. It was worked at that time and also in later years for iron ore; but the manganese is said not to have been mined until about the year 1882. The property is owned by Mr. G. W. Bradley. It was worked by Carnegie Brothers and Company in 1890, but mining was discontinued before the end of that year.

The iron ore is an ordinary brown hematite. The manganese is in both the crystalline and massive forms, fibrous crystals of pyrolusite sometimes lining cavities in the massive ore. There are also found nests of short prismatic crystals with strongly striated surfaces, an iron-gray color, and a hardness greater than that of pyrolusite. Dr. S. L. Penfield, of Yale College, has very kindly measured some of the angles of these crystals and has found them to closely resemble those of true manganite.

The massive manganese ore often occurs in the form of geodes, or "pot ore," which are sometimes filled with water and locally known by the miners as "water-holes." Occasionally well formed stalactites of massive black ore are found in the interiors of such cavities.

The iron and manganese ores occur in pockets and nests in a yellow and sometimes red, lead-gray, or white clay. The two ores are in some places together in the same pocket; at others in separate ones. When mixed, they are associated in all proportions. The yellow and red clay, locally known as ochre, have been used as a pigment, and several houses in South Wallingford are painted with the yellow material.

The ore-bearing deposit occurs at the contact of the Cambrian quartzite and the overlying limestone. The quartzite forms the mass of a rugged ridge, running in a general north-south direction; and the limestone crops out on the lower part of its western slope, extending thence into Otter Creek valley. The quartzite is a hard translucent rock, sometimes showing no trace of its original sandy structure. The limestone is usually

of a gray or buff color, massive or semi-crystalline, and is much contorted. The general dip is almost vertical and the general strike is a little east of north.

In immediate contact with the sandstone, and between that and the ore-bearing deposit, there is often a stratum, several feet thick, of pure snow-white clay, which has been worked as a source of pottery clay. It sometimes contains masses of manganese ore.

The surface outcrop of the ore deposit is obscured by glacial boulders and other drift materials for a depth of from ten to sixty feet, so that its extent can be seen only in the underground workings. The total breadth of the clay deposit, as measured by old drifts, is said to have been found to vary from a hundred and fifty to three hundred feet, with ore scattered through it at intervals. Some of these drifts, however, on account of the disturbed and curved condition of the rocks, went diagonally across the deposit, so that the supposed width is probably much greater than the actual width.

A tunnel, which is said to be 1,700 feet long, has been run into the hill along this deposit, and numerous small drifts and shafts have been made at various points along its course. The tunnel was started at the foot of the ridge and was run in an easterly direction through the limestone until the ore bed was

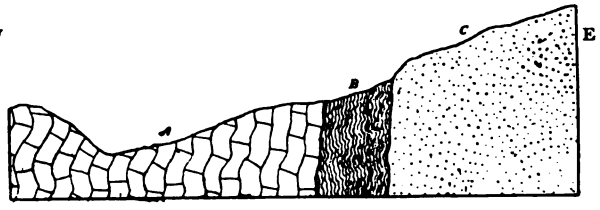

Figure 29. *Section near South Wallingford, Vermont, showing the mode of occurrence of the manganese-bearing clay.*

A. Limestone.
B. Manganese-bearing clay.
C. Quartzite.
Horizontal scale: 1 inch—300 feet. Vertical scale: 1 inch—100 feet.

reached. Here it was turned north and continued along the deposit. Considerable difficulty was experienced from the water, which runs into the tunnel and tends to cave in the clay, neces-

sitating heavy timbering. The accompanying general section shows the relation of the ore bed to the enclosing rocks.

This deposit doubtless represents the decomposition of a bed which was once in the form of rock carrying the ore in the same, or nearly the same way as the clay now carries it. The rock has been decomposed in place, and the clay, which represents its residual product, occupies the same interstratified position as the rock formerly held. The original rock was probably a siliceous material with more or less admixture of shale or schist. As evidence that the ore was once imbedded in the solid rock, it may be stated that fragments of quartzite often containing masses of ore are found in the clay, and are especially noticeable near the quartzite on the east side of the deposit. These probably represent the more resistant siliceous parts of the original ore-bearing rock, which have so far escaped decay. The following analyses show the composition of the manganese ore from this mine:

*Analyses of manganese ore from South Wallingford, Vermont.**

CONSTITUENTS.	UNWASHED ORE.				WASHED ORE.		
	1.	2.	3.	4.	5.	6.	7.
Manganese	20.141	26.182	20.602	34.393	44.107	35.000	48.778
Iron	33.383	26.104	32.128	14.650	7.180	25.000	4.970
Silica	9.520	10.000	7.480	12.500	9.230	3.100	7.900
Phosphorus	0.088	0.064	0.073	11.151?	.....	0.061	0.111

The Brandon mine.—The town of Brandon is on the Central Vermont Railroad, in Otter Creek valley, Rutland county, Vermont. Manganese and iron have been found two and a half miles northeast of the town in a small tributary to the main valley. According to Dr. D. W. Prime, of Brandon, iron was mined here about seventy-five years ago, and has been worked to a greater or less extent at intervals since that time. Part of the ore was used in making pig-iron at Brandon and at other furnaces in the surrounding country, and part was sent to New York,

* Mineral Resources of the United States, 1888, p. 132.

Boston, and other places as a source of paint. In later years, however, the iron ores of Pennsylvania have replaced it in the paint market. The manganese ores were not worked until shortly before 1860, and have been mined only at intervals since then. In 1889 and 1890, the deposit was worked by Carnegie Brothers and Company, but no work is being done at this locality at present (December, 1890), and the old pits have mostly caved in, making it difficult to see much of the nature of the deposit.

The iron ore is a brown hematite and is found in far larger quantities than the manganese. The latter occurs in the form of nodules and irregular masses from a fraction of an inch to twelve inches or more in diameter. The characteristic form, however, is that of small kidney-shaped masses, an inch or more in diameter, of a massive structure and a steel-blue or black color. The larger masses occasionally contain cavities lined with crystalline ore, mostly pyrolusite. Sometimes the ore shows a concretionary structure; at other times it is soft, and earthy, containing numerous grains of transparent, angular and rounded sand.

The iron and manganese ores occur in a brown or white clay, in the form of pockets or scattered masses more or less closely compacted. At times both ores are in one pocket, at others they are separate. The deposit occupies the bottom of the valley in which it is situated. On the east side the Cambrian quartzite, occasionally containing micaceous strata, forms a rugged north and south ridge, and strikes in the same general direction, dipping almost vertically. On the west are the overlying white dolomitic limestones and marbles of Otter Creek valley, striking in a general direction parallel to the quartzite.

In sinking on the ore-bearing deposit, the dolomite is said to have been reached on the west side, while, to the depth that was reached on the east side, no rock was found in place, but quartzite would probably have been reached at a greater or less distance in that direction. The clay deposit is covered over by from three to twenty feet of gravel and boulders, so that its

exact extent cannot be seen, but it probably underlies the valley for a breadth of several hundred yards.

Lignite has been found in the same locality in a clay similar to that containing the iron and manganese ores, and has been mined and shipped to New York. Well preserved fossil plants and fruits occur in the lignite and were early determined as Tertiary, probably Pliocene, by Professor E. Hitchcock.* Specimens afterwards examined by Professor Leo Lesquereux were determined by him also as belonging probably to the Upper Tertiary.†

The rocks on either sides of the valley are very much like the rocks on either side of the ore-bearing deposit of South Wallingford, which is undoubtedly in Paleozoic rock decomposed in place, and not a later deposit in Tertiary strata. Hence it seems most probable that the deposit of Brandon has been derived from a deposit similar to that at South Wallingford, which possibly underlies the Tertiary beds; that the materials have been more or less changed in position, mixed with foreign matter, especially the vegetable matter forming the lignite beds, and laid down again; that this alteration process was not confined to Tertiary times, but that it may also have gone on before, during, and after that period.

Iron and lignite deposits have been found in positions somewhat similar to that of Brandon in several places in Pennsylvania, and have been described by Professor J. P. Lesley‡ at Pond Bank near Chambersburg; by Frederick Prime, jr., § at Brown's iron mine, Ironton, Lehigh county; and by H. C. Lewis ‖ at and near Marble Hall in Montgomery county. It was formerly a matter of very considerable discussion whether these deposits represent simply local Tertiary areas or whether the whole iron bearing belt, running through the Appalachian Valley from

* Geology of Vermont, 1861, p. 717; Amer. Jour. Sci., 2nd series, Vol. XV., 1853, p. 104.

† Amer. Jour. Sci., 2nd series, Vol. XXXII., 1861, p. 362-363.

‡ Proc. Amer. Philos. Soc., Vol. IX., p. 463.

§ Second Geol. Survey of Penna., Report DD., p. 76.

‖ Proc. Acad. Nat. Sci. Phila., October 27, 1879.

Vermont to Alabama, represents the same horizon. Hitchcock,* in 1861, was the first to propose the theory that the whole belt represented a Tertiary deposit, and this theory is advocated by Lewis. Professor Lesley and others believe that there are isolated areas of Tertiary deposits, but that elsewhere the iron ore represents simply the weathered outcrop of a Paleozoic deposit, possibly more or less altered in structure on the surface. Later investigations have still further strengthened this supposition, and the experience of the writer in the manganese deposits in the same belt of country is entirely in accord with it.

The first analysis below, made by Prof. Olmsted, represents the composition of a specimen of ore from the Brandon mine; but it must have been a selected sample, as car-load shipments of ore from this mine would not contain so large a percentage of manganese.

Analysis of manganese ore from Brandon, Vermont.†

Red oxide of manganese	81.88
Manganese	2.22
Oxygen	2.74
Silica	3.60
Water	9.75
	99.69
Manganese	58.62

The following two analyses represent car-load shipments of manganiferous iron ore from Vermont, from either Brandon or South Wallingford:

Analyses of manganiferous iron ore from Vermont.‡

	(1)	(2)
Manganese	20.369	19.706
Iron	31.648	29.268
Silica	12.770	14.000
Phosphorus	0.125	0.145
Moisture	5.000	8.000

* Geology of Vermont.

† Prof. Olmsted, Geology of Vermont, 1861, p. 811.

‡ These analyses were kindly furnished the Survey by Mr. H. M. Curry, of the firm of Carnegie Bros. and Co.

Other localities in Vermont.—Besides the places already described, manganese has been found in greater or less quantities in many other parts of Vermont, not only in the Otter Creek valley but elsewhere, and at some of them it has been worked. At most of them, however, it is in small quantities. Among the localities mentioned in the Geology of Vermont are: Bennington and Stamford in Bennington county; Pittsford and Chittenden in Rutland county; Plymouth in Windsor county; Topsham in Orange county; Bristol and Monkton in Addison county; Colchester in Chittenden county; Irasburg and Coventry in Orleans county.

At Bennington the ore is said to have been used to give a gray color or a clouded shade to pottery.*

THE MANGANESE DEPOSITS OF NEW YORK.

Manganese has been found in many places in the state of New York, but, so far as known, it is in small quantities, and it has not been mined to any important extent. Ores in the forms† of wad or of other oxides in a more or less pure condition, have been found in Cattaraugus, Allegany, Lewis, Essex, Columbia, Orange, and other counties. Near Sing Sing, in Westchester county, a compact, black oxide of manganese containing small quantities of copper, occurs in dolomite. Oxide of manganese occurs in nests and geodes in the hematites of Unionvale, Dutchess county; and silicate of manganese is found with the magnetic iron ores of the primitive rocks in Essex and Warren counties.‡ Babingtonite, a silicate of iron, manganese, and lime, with a small quantity of titanium, is found at Gouverneur, in St. Lawrence county. It resembles some forms of pyroxene.

THE MANGANESE DEPOSITS OF PENNSYLVANIA.

In Pennsylvania manganese is found in small quantities in pockets in many of the iron ore beds, and a limited amount has been mined in working the latter ore, but the production of manganese has played no important part in the industries of the

* Geology of Vermont, 1861, p. 811.

† Lewis S. Beck, Nat. Hist. of New York, Pt. III., Mineralogy, 1842, pp. 53-54.

‡ Ibid, pp. 406-407.

state. The ore has been worked at only a few places; among others at Ironton, in Lehigh county. Manganese also occurs in small quantities with some of the iron ores of Northampton, Berks, Blair, Centre, and Huntingdon counties, and especially at several places on Broad Mountain. Manganiferous iron ore is found near Myer's Mill in York county.*

The spathic iron ores found in the Carboniferous rocks often contain small quantities of manganese, varying from less than 0.50 per cent to 4.5 per cent of carbonate of manganese, equal to from 0.23 to 2.15 per cent of metallic manganese. †

Earthy ferruginous oxides of manganese and carbonate of manganese, as well as manganiferous garnets have been found three miles south of West Chester; and black oxide of manganese occurs in very small quantities in gneissic rocks on Pennypack Creek, at the mouth of Sandy Run, three miles from Bustleton. ‡

The following analysis by Andrew S. McCreath shows the composition of manganese ore from the land of the Ironton Railroad Company, Ironton, Penn.:

Analysis of manganese ore from Lehigh county, Penn.§

Manganese peroxide	77.960
Manganese protoxide	4.320
Ferric oxide	3.660
Alumina	0.711
Cobalt oxide	0.390
Nickel oxide	trace
Copper oxide	trace
Lime	0.770
Baryta	0.152
Magnesia	0.236
Potash	3.042
Soda	0.368
Water	3.980
Sulphuric acid	trace
Phosphoric acid	0.149
Silica	4.845
	100.583
Manganese	52.631
Iron	2.562
Phosphorus	0.063

* Mineral Resources of the United States, 1885, pp. 342-343.

† H. D. Rogers, Geology of Penn., 1858, Vol. II., p. 739. Andrew S. McCreath, Chemical Analyses, Second Geol. Survey of Penn., 1879, Vol. M. M., pp. 159-184.

‡ Geo. W. Carpenter, Amer. Jour. Sci., 1st series, Vol. XIV., 1828, pp. 4, 12.

§ Andrew S. McCreath, Second Geol. Survey Penn., 1879, Vol. M. M., p. 218.

The following analyses show the composition of manganese ores from Lehigh and York counties. No. 1 was made by Henry Pemberton, jr., No. 3 by Andrew S. McCreath:

Analyses of manganese ores from Lehigh and York counties, Pennsylvania. *

CONSTITUENTS.	(1) Lehigh county.	(2) Ironton, Lehigh county.	(3) Myer's Mill York county.
Manganese	56.580	17.648	15.934
Iron	.....	26.400	32.400
Insoluble residue, silica, etc.	.....	21.860	.....
Phosphorus	Trace	0.095	0.651
Sulphur	.....	0.010	0.027

THE MANGANESE DEPOSITS OF MARYLAND.

Manganese has been mined in small quantities in several places in Maryland, but at present no work is being done. Among the localities that have been operated are Brookeville in Montgomery county; and on the north side of the Potomac River, opposite Harper's Ferry,† Manganese has also been found near Mechanicsville,‡ Montgomery county, and on Bear Creek, Yohogany Valley,§ but the quantity has so far proved small.

THE MANGANESE DEPOSITS OF VIRGINIA.—*Location and general features.*

The principal manganese deposits of Virginia are in the Valley of Virginia. The quartzite‖ with which the deposits are associated skirts the northwestern flanks of the Blue Ridge in a series of irregular mountains and hills; and forms the eastern barrier of the Valley of Virginia in many places through the state. It reaches to the base of the mountains and at times underlies

* Mineral Resources of the United States, 1885, p. 343.

† Mineral Resources of the United States, 1885, p. 344.

‡ J. T. Ducatel and John H. Alexander, Amer. Jour. Sci., 1st series, Vol. XXVII., 1835, p. 20.

§ Ibid., p. 33.

‖ See pages 376 to 380.

some of the lower country. Here it comes into contact with the "valley limestone" of Rogers, and it is at and near the contact of the two formations that the manganese ores have been found, often associated with far greater quantities of brown hematite. Manganese ores are also found to the west of the Valley of Virginia, in the New River and Cripple Creek region and elsewhere; also in the James River valley, and in the coastal area of the state.

THE MANGANESE DEPOSITS OF VIRGINIA.—*Valley of Virginia.*

The Crimora mine.—The Crimora mine is situated in Augusta county, Virginia, in the valley of the Shenandoah River, seven miles northeast of the town of Waynesborough. It is two miles east of the river and at the foot of the northwestern slope of the Blue Ridge. It is connected with the Shenandoah Valley Railroad at Crimora station by a branch line.

The Crimora mine was originally owned by Mr. Flannigan, of Charlottesville, and was bought in 1867 by a stock company. This company operated for two years, and then abandoned work. From 1869 until 1882 the property was worked at intervals by Mr. S. W. Donald in the interest of the former company, but in the latter year it was leased by James B. White and Company, of Pittsburg, who commenced extensive operations.* It is now operated by the American Manganese Company. The property has produced more manganese ore than any other mine in the United States, and its output has comprised by far the larger part of the whole product of the state of Virginia. In 1885 it gave three-quarters of the product of the United States, and in 1886 it yielded 94 per cent of the manganese ore mined in Virginia, and 64 per cent of that mined in the United States. In 1887 it yielded 96 per cent of the production of Virginia and 55 of that of the United States; in 1888 it yielded 91 per cent of the production of Virginia and 55 per cent of that of the United States. Formerly the ore was known as the "Waynesborough ore" from its point of shipment at that town. It is now know as "Crimora ore."

* Mineral Resources of the United States, 1883-4, p. 551.

The following table shows the production of manganese from this mine since it was first opened up to 1888: *

Production of the Crimora mine, Virginia.

	Long tons.
Prior to 1869	5,684
May, 1869, to February, 1876	280
February, 1876, to December, 1878	2,326
December, 1878, to December, 1879	1,602
1880	2,963
1881	2,495
1882	1,652
1883	5,185
1884	8,804
1885	18,212
1886	19,382
1887	19,100
1888	16,100
Total production up to 1888	103,785

The manganese ore of the Crimora mine occurs mostly as psilomelane and pyrolusite, the former being by far the more plentiful. Other oxides are possibly present in smaller quantities, but they have not yet been identified. The psilomelane is in the form of botryoidal, mammillary, or stalactitic masses of a black or steel-blue color; the pyrolusite is of a highly developed crystalline structure, and forms a mass of brilliant black, radiating crystals. Both the massive and crystalline ores are often intimately mixed. The masses of ore vary from small nodules a fraction of an inch in diameter to large bodies of many tons in weight. In one case, a solid mass thirty feet long and five feet thick, is said to have been found.

The ore is imbedded in a stiff clay, generally of a brown or yellow color, but sometimes white or purplish-red. This clay is overlain by a bed about twenty feet thick of pebbly drift, in which fragments of ore are sometimes found. The manganese here, however, has been derived from the underlying deposit, and it is the latter bed that contains the main masses of ore. The ore-bearing clay varies in thickness from ten or fifteen

* Mineral Resources of the United States, 1888, p. 133.

feet to over two hundred and seventy-six feet. Several borings have been made and the deepest is said to have reached the latter depth without finding the bottom of the clay. In the deeper borings the bed was found to assume a shaly structure, which was probably the original condition of the whole deposit as explained on pages 385–386.

The manganese exists in very variable quantities, being in some places almost entirely absent, and in others composing a large part of the mass of the bed. Fragments of sandstone and quartz are occasionally found in the clay. The latter sometimes have a cherty appearance, are angular, partly decayed on the outside, and are often cemented together by manganese ore. These siliceous rocks probably represent the undecomposed remains of the original solid bed. (See page 387.)

The Crimora property is situated at the base of a recess in the mountains which to the north, south, and east, rise up abruptly, reaching a height on the east of some fifteen hundred feet above the Shenandoah River. To the west a low country extends from the mine to the river. The mountains are composed of sandstone or quartzite which varies from a comparatively soft to very hard translucent rock.

Across the mouth of the recess in which the property is situated, the clay is thin, and the sandstone is often reached within a depth of a few feet. In towards the mountains, that is to the east, it becomes gradually thicker until it reaches its maximum depth of over two hundred and seventy-six feet; and then becomes thin again, finally running out altogether when the mountains are reached.

The manganese ore at the Crimora mine has been worked at different times in shafts and in open pits. In the process of mining, the ore is separated from the clay that adheres to it by first passing it through a trough in which a shaft, armed with flanges arranged as a broken helix, revolves longitudinally. A stream of water runs through the trough, and the flanges force the ore against it, finally discharging it on to a revolving screen fed by a stream of water. The first screen discharges into a second, and the ore is passed thence on to an apron-belt, where

the loose lumps of rock and clay are picked out and the clean ore carried to the bins. The small sized ore which goes through the screens is further washed in jigs.

The following analyses represent the composition of car-load shipments of manganese ore from this property.

*Analyses of manganese ore from the Crimora mine, Virginia.**

Manganese.....	49.16	48.53	50.54	48.16
Iron.....	1.75	1.99	1.96	4.57
Silica	9.80	10.20	10.12	10.30
Phosphorus..... ..		0.103	.....	0.095
Moisture.....	6.00	3.00	3.00	3.00

The Lyndhurst mine.—Lyndhurst is a station on the Shenandoah Valley Railroad, in Augusta county, about twelve miles southwest of Crimora. Manganese has been found and mined on a small scale two and a half miles southeast of the town. This property was originally opened in 1859 by Mr. Sibert, who mined over two hundred and fifty tons of ore.† In 1885, the property was again opened, this time by the Virginia Manganese Mining Company. They have since suspended work, and the property is now (December, 1890) idle.

The manganese here is of much the same nature and occurs in much the same associations as at Crimora, though it is, so far as the deposit has been explored, in much smaller quantities. The same range of sandstone mountains that has been described passes immediately east of the ore-bearing bed, which underlies the low country at their base. The deposit extends thence west to beyond a small creek which passes the mountains half a mile from their base, and is a tributary of the South River fork of the Shenandoah River. Manganese is not found continuously throughout this area, but only at intervals, occasionally cropping out in the soil and elsewhere covered by barren clay. The ore generally consists of porous bodies composed of a honeycombed

* These analyses were kindly furnished the Survey by Mr. H. M. Curry, of the firm o Carnegie Brothers and Company.

† Mineral Resources of the United States, 1885, p. 317.

mass of stalactitic branches from a sixteenth to an eighth of an inch in thickness. It is a black, iron-gray, or dark steel-blue, massive ore, though smaller quantities of crystalline pyrolusite also occur.

Fragments of sandstone studded with small, flat nodules of ore, as well as masses of brecciated sandstone cemented with manganese, are of frequent occurrence in the ore-bearing clay. These rocks vary from a few inches to a few feet in diameter, and are doubtless the remains of a once continuous ore-bearing stratum, carrying ore just as the clay now carries it. On the slope of the mountain, to the east of the ore-bearing deposit, fragments of sandstone are found with cracks filled with manganese ore. They are, however, of only local occurrence and do not represent any extensive deposit.

The Buena Vista mines.—Buena Vista is in Rockbridge county, on the Shenandoah Valley Railroad, at the junction with the Lexington branch of the Chesapeake and Ohio Railway. It is on the northwestern slope of the main range of the Blue Ridge and to the east of the North River, a branch of the James River. It is a new town, laid out by the Buena Vista Company near the old site of Loch Laird, with the object of developing the iron ores of that neighborhood.

The manganese generally exists as irregular bodies in association with brown hematite, though sometimes it is found alone. The iron ore varies from a loose, porous variety to a compact, massive, brown ore. The manganese occurs in both the massive and crystalline conditions, the former being in the preponderance. Both the iron and manganese are found as interbedded deposits in clay, in association with shale, limestone, and quartzite.

The rocks are much disturbed and frequently stand on end, or are arched into small anticlinal ridges. The clay beds form interstratified deposits with these rocks, and dip and strike conformably with them. They doubtless represent the residual product of the decay, in situ, of the rock which once carried the ores.

The hematite occurs just east of the town, in pockets and beds varying from six feet to many times that in thickness. It frequently contains minor pockets or lenticular layers of the same brown or yellow clay which encloses it on either side. The

manganese is found in variable quantities: in some places it exists as pockets in the brown hematite or the associated clay, in others as interbedded layers, very irregular in form and extent, and varying from a few inches to two or three feet in thickness. It does not appear to be confined to any one position in the iron ore beds, and it often differs considerably from that ore in its greater tendency to a nodular or concretionary form.

Besides the manganese found in the hematite beds, the same ore occurs separately on the land of Peter Matthews, near Buena Vista. It is found in clay overlying a small sandstone hill, and is in kidney-shaped masses, from an inch to a foot or more in diameter, of an iron-gray to a black color, with a marked concentric structure. It is mostly massive, though some crystalline ore is also found.

The Houston mines.—The Houston mines are situated in Botetourt county, Virginia, on the Shenandoah Valley Railroad, fifteen miles northeast of Roanoke. Like the other properties already mentioned, they lie on the western slope of the Blue Ridge, but higher up on the mountains than either Crimora or Lyndhurst. This property was worked for many years as a source of manganiferous iron ore, though limited quantities of manganese were also mined. Lately the property has been acquired by J. B. White and Company, and attention is being paid to the purely manganese ores.

In 1888, 985 tons were mined, of which amount 100 tons were high grade and were used for chemical purposes, and the remaining 885 tons were shipped to Carnegie Brothers and Company for steel purposes. *

The manganese ore is of both the massive and crystalline varieties, the latter often being pyrolusite, and is associated with brown hematite in different ways: it is often disseminated through the iron ore, or encrusts it as a massive or crystalline coating; while elsewhere comparatively pure bodies of one ore are in proximity to similar bodies of the other. Both the manganese and iron occur in a more or less sandy clay which is often brilliantly mottled, white, yellow, or dun, to brown, red and

* Mineral Resources of United States, 1888, p. 133.

purple. The ore is unequally distributed throughout it in nodules and pockets. The clay bed has been worked to a depth of over a hundred feet without reaching the bottom. Frequently masses of sandstone and quartzite are found in it, containing layers and nodules of iron and manganese ores. These fragments are often several feet in diameter, and doubtless represent a former solid bed of ore-bearing rock, which by its decay has given rise to the present ore-bearing clay. The ore-bearing deposit lies on the slope of a sandstone mountain, and nodules of manganese are frequently seen in the solid rock near the contact with the ore bed.

Other localities in the Valley of Virginia and in the country immediately to the west.—Besides the deposits already described, numerous others occur elsewhere in the Valley of Virginia and the country immediately to the west. Most of these have been worked to only a limited extent and the quantity of manganese shipped from them has been small. Some of them occur in association with quartzites or sandstones like those in the localities already described, while others occur in shales and limestones belonging probably higher up, geologically, in the Silurian system. The following list includes the larger number of such localities, and the statistics of production given in it are taken mostly from the papers of Mr. Jos. D. Weeks in the annual reports of the Mineral Resources of the United States from 1885 to 1888:

The Paddy Mills mine.—The Paddy Mills mine is in Frederick county, Virginia, and was worked before 1861.

The Van Buren furnace.—The Van Buren furnace is in Shenandoah county, nine miles from Woodstock, the nearest railway station. Manganese is said to have been shipped before 1861, but none has been mined since 1873. Operations are said to have been suspended on account of lack of transportion facilities.

The Powell's Fort mine.—The Powell's Fort mine is situated at Powell's Fort, Shenandoah county. It has been worked on a small scale intermittently for many years, and a thousand

tons of ore are said to have been shipped up to 1885. It is owned by the Manganese and Iron Company of Baltimore.

Milnes station.—Milnes station is on the Shenandoah Valley Railroad, in Page county. Manganese associated with brown hematite has been mined in the neighborhood on the land of the Shenandoah Iron Company. The shipments in 1884 and 1885 are said to have been 208 tons and 2,155 tons respectively.

The Patrick tract.—The Patrick tract is near the Crimora mine in Augusta county, and has been worked by the Old Dominion Manganese Company.

The Kennedy tract.—The Kennedy tract is in Augusta county, on the Shenandoah Valley Railroad. The ore occurs here as pure manganese ore and manganiferous iron ore. In 1859 Mr. Sibert is said to have mined 100 tons of manganese ore on this property.

Blue bank, Newton bank, Kelly bank, etc.—These properties and several others are situated in the Valley of Virginia at or near the line of Augusta and Rockbridge counties. Manganese is found on them in connection with brown hematite and manganiferous iron ore. They have all been worked to a greater or less extent, generally in search for iron ore, though small quantities of manganese ore have also been mined.

Midvale.—At Midvale in Rockbridge county, the Midvale Manganese Company mined 250 tons of manganese ore in 1887.

Wythe county.—Manganese ores have been found near Wytheville in Wythe county, and about 300 tons are said to have been mined in 1887.

Besides the above mentioned localities manganese has been found in many other places, but very little mining has been done on them. Among them are: near Harper's Ferry in Jefferson county; the Paddy Mill's mine in Page county; Overall in Warren county; Marksville in Page county; Elkton and the Guy's Run estate in Rockbridge county; Gap Mountain in Craig county; the Buckeye and Spruce River Mountains, Flat Top Mountain, and elsewhere in Giles county; Pulaski, Bland, Tazewell, Smythe, and other counties.

THE MANGANESE DEPOSITS OF VIRGINIA.—*New River and Cripple Creek region.*

Besides the deposits already mentioned, numerous others have been found along the line of the Cripple Creek extension of the Norfolk and Western Railroad. They have been described and analyses have been given by Messrs. McCreath and d'Invilliers.* The ores have been mined to a small extent, but generally, as in many other parts of Virginia, in connection with, and subordinate to work on the iron ore deposits with which they are usually associated.

THE MANGANESE DEPOSITS OF VIRGINIA.—*James River valley.*

General features.—The James River rises in the mountainous region of West Virginia, and cuts directly across the northeast and southwest ranges of mountains, intersecting the Valley of Virginia south of Lexington, and passing through the Blue Ridge at Balcony Falls. Thence it pursues a southeasterly course to Lynchburg, where it turns sharply to the northeast, and follows the direction of the mountains to the southern part of Albemarle county, and here it again reverts to its former course and continues to the sea.

The manganese-bearing sandstone or quartzite has been reported in several places in the region of the northeast bend of the river below Lynchburg, especially in Campbell, Nelson, and Albemarle counties. Mr. James E. Mills, who was the first to operate manganese in the James River region, after speaking of the sandstone in the Valley of Virginia, says:† "Another outcrop, or series of outcrops which I have not seen reported heretofore, lies nearly parallel to the former and from 20 to 25 miles distant in a southeasterly direction. It follows near the James River where the latter flows in the general northeast course of the geological structure of the country, from near its great bend in Campbell Co. a few miles below Lynchburg, to where it turns eastward near the dividing line of Nelson and Albemarle counties. I have traced it for several miles to the southwest of

* Andrew S. McCreath and E. V. d' Invilliers, The New River-Cripple Creek Mineral Region of Virginia, issued by the Norfolk and Western Railroad, 1887.

† American Chemist, August, 1871, pp. 49-50.

the bend of the river in Campbell Co. and it is reported as existing still further in that direction." Several manganese openings have been made in this region, among the most important of which, as regards the amount of ore shipped, are the Cabell, Bagley, and Mt. Athos mines.

The Cabell mine.—The Cabell mine is in Nelson county, two miles from the James River at Warminster. It was opened by Mr. J. E. Mills about 1867 or 1868, and represented the first systematic work in manganese mining in Virginia. Up to 1871, 4,500 tons of ore were shipped. The property is not being worked at present. The ore occurs in the solid rock and not in the residual clay as in most localities. Mr. Mills,* in speaking of the occurrence of the manganese here, says: "The beds of manganese form irregular patches of strata, lying on the whole nearly in the planes of stratification, but often cutting across the strata for short distances; sometimes dividing into two or more parts, one turning to the right and one to the left, and sometimes sending off shoots into the sandstone. The thickness too varies exceedingly; I have seen beds bulge in two or three instances to ten feet thick." This deposit is of especial interest as showing the manganese in place in the original rock.

The following analysis by Mr. John Pattinson, of Newcastle, England, represents the composition of a cargo of 186 tons of ore shipped there from this property by Mr. Mills: †

Analysis of manganese ore from the Cabell mine, Virginia.

Manganese peroxide	65.20
Manganese protoxide	4.75
Ferric oxide	6.20
Alumina	3.93
Lime	1.43
Magnesia	0.41
Water (combined)	3.02
Phosphoric acid	0.42
Sulphuric acid	0.30
Silica	14.20
	99.86
Manganese	44.87
Iron	4.84
Phosphorus	0.18

* American Chemist, August, 1871, p. 50

† Ibid., p. 51.

The Bagley mine.—The Bagley mine is half a mile southwest of the Cabell mine, and the ore, according to Mr. Mills, occurs in the same associations. About two thousand tons of ore* are said to have been shipped from the property.

The Mount Athos mine.—The Mount Athos mine, also known as the Leets mine, is in Campbell county, near Mount Athos station on the Norfolk and Western Railroad. The manganese ore is said to occur in association with iron ore in pockets and as "buttons."

The following table gives the production of the Mount Athos mine from 1880 to 1888 inclusive:†

Production of the Mount Athos mine, Virginia.

	Tons.
1880	104
1881	50
1882	130
1883	40
1884	76
1885	500
1886	191
1887	?
1888	225

Other localities in the James River valley.—Manganese has been found in several other places in the Piedmont and Midland regions of this valley, but only limited quantities have been mined. Among these localities are: The Bishop mine, near the Mount Athos mine just described; the Simpson tract at Midway Mills, Nelson county; the Davis mine, Nelson county; Pittsylvania, Spottsylvania, Louisa, Appomattox, and other counties.

THE MANGANESE DEPOSITS OF VIRGINIA.—*The coastal region.*

City Point.—City Point is in the coastal area of Virginia, in Prince George county, on the lower waters of the James River. Manganese is said to have been found near here in association with brown hematite in Tertiary beds. Several hundred tons of ore were mined.‡

* Mineral Resources of the United States, 1885, p. 312.

† Ibid., 1885, 1886, 1888.

‡ Ibid., 1885, p. 309.

THE MANGANESE DEPOSITS OF NORTH CAROLINA.

Manganese has been found in several places in the western part of North Carolina, but most of the deposits are small, and only limited quantities of ore have been shipped from any of them. The ore is in some places in the form of oxides associated with quartzite, as in the Valley of Virginia; in others it occurs as silicates in the crystalline rocks. As elsewhere in the Appalachian Mountains it is frequently mixed with iron ores. Among the localities where it is reported to exist are: the Perkins mine, ten miles west of Lenoir, and also at a locality five miles west of Lenoir, Caldwell county; ten miles north of Dobson, Surry county; half a mile west of Blue Ridge Gap, Mitchell county; at Warm Springs, Madison county; in Cherokee, Catawba, Nash, Cabarrus, Jackson, Stokes, Chatham, Gaston, and other counties.

A large part of the ores in the counties mentioned are in the form of silicate of manganese, which contains too much silica to be available as a source of manganese. In some of the localities, however, the oxides of manganese occur, and are available for commercial purposes if they can be found in sufficiently large quantities. North Carolina produced only fourteen tons of manganese ore in 1887 * and fifty tons in 1888 †.

THE MANGANESE DEPOSITS OF SOUTH CAROLINA.

What has been said of the manganese ores of North Carolina, is also true of those of South Carolina, except that in the latter state smaller quantities have been found, and very little ore has been mined. A small amount is said to have been shipped from near Greenville, Greenville county; and from the Dorn Lands, near McCormick ‡; but South Carolina cannot at present be classed as a manganese-producing region.

The following analysis shows the composition of a sample of South Carolina manganese ore:

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* Mineral Resources of the United States, 1887, p. 145.

† Ibid., 1888, p. 124.

‡ Ibid., 1886, p. 193.

*Analysis of manganese ore from South Carolina.**

Manganese	45.018
Iron	2.750
Silica	8.100
Phosphorus	0.085
Moisture	9.000

THE MANGANESE DEPOSITS OF EAST TENNESSEE.

General features.—The eastern part of Tennessee is comprised in the main range of the Appalachian Mountains, and consists of a series of northeast and southwest ranges. On the the east of the Valley of Tennessee, which represents the southwesterly continuation of the Valley of Virginia, the predominating ranges are numerous local developments of the Blue Ridge, of which the Unaka and Great Smoky Mountains, with the subordinate Holston, Iron, Meadow Creek, Chilhowee, and other mountains, are among the important features. On the west of the valley are Clinch Mountain and the Cumberland Range.

Very little manganese ore has been shipped from this region, and a few hundred tons would probably include the whole production. Its existence in many places has been known for a long time, and it is said to have been mined near Whitfield, in Hickman county, as early as 1837, but distance from railway transportation has doubtless been the cause of the lack of attempts to mine the ore in other places. Most of the discoveries have been made on the northwestern flanks of the Blue Ridge, where the ore is usually associated with brown hematite in quartzites or in the immediately overlying shales and limestones, as already explained on pages 385–388.

The rocks are all much disturbed and are thrown into a series of anticlinal and synclinal folds. †

Shady Valley.—Shady Valley is situated in Johnson county,

* This analysis has been kindly furnished the Survey by Mr. H. M. Curry, of the firm of Carnegie Brothers and Company.

† For further details concerning the geology of the region see:

A Geological Reconnoissance of the State of Tennessee, by James M. Safford, State Geologist, 1856.

The Geology of Tennessee, by James M. Safford, State Geologist, 1869.

The Resources of Tennessee, by J. B. Killebrew assisted by James M. Safford, 1874.

in the extreme northeast corner of Tennessee, sixteen miles southeast of the Shenandoah Valley Railroad at Abingdon, Virginia. The valley runs in a general northeast and southwest direction, and represents the northeastern part of the main valley between Holston Mountain on the northwest, and Iron Mountain on the southeast. It varies from two or three miles to less than half a mile in width, in places being little more than a rocky gorge. It is drained by a small stream, which forms one of the head waters of the Holston River.

Brown hematite and manganese ore are found at intervals throughout a large part of this valley, and the town of Damascus has been laid out at its northeast end, in Virginia, just across the state line, by the Damascus Enterprise Company, with the intention of utilizing the ores. The manganese has been little more than prospected, but the iron ore has been worked and smelted in small open forges for more than a hundred years.

Holston Mountain, which forms the northwest barrier of Shady Valley, is composed largely of sandstone or quartzite, but on its lower slopes the associated limestones and shales appear. The latter beds, as well as the upper part of the quartzite, are much decomposed and often exist as clay, sometimes more or less sandy and containing rocky fragments which represent the undecayed parts of the original beds. The iron and manganese ores are found in these clay deposits.

The iron ore varies from a massive brown hematite to a porous, black variety. Sometimes where it comes in contact with sandstone, it is highly siliceous, but at others it is comparatively free from that impurity. The manganese generally occurs as a steel-gray or black, porous mass of thin stalactitic branches, and more rarely in mammillary bodies. Sometimes crystals of pyrolusite line the cavities of the massive ore.

The iron and manganese ores occur as interbedded lenticular deposits or pockets, the iron ore being in far the larger quantities. In some places the two ores occur together in the same bed, often coming into sharp contact; in others they are in separate beds, comparatively free from any admixture with each other. The iron ore deposits vary from a few inches to over

ten feet in thickness; the manganese deposits vary from a few inches to three feet. The latter thickness for the manganese deposits, however, is rare.

In one place near the bottom of Shady Valley, a series of shales, quartzites, and siliceous blue limestones occurs in a bluff about fifty feet high. These beds probably represent the original condition of the ore-bearing strata which overlie the quartzite. Pebbles of manganese ore in a black maganiferous clay are frequently found in the hollows in the surface of the limestone, and have doubtless been derived from the associated rocks by decay.

Small quantities, often only a stain, of manganese are found in situ in the quartzite in various parts of Holston Mountain, but most of the ore is in the residual clay derived from the overlying beds.

Other localities in Tennessee.—Among the other localities where manganese has been found in Tennessee may be mentioned:

Greene county.—Manganese ore is found in Greene county,* in association with a manganiferous iron ore which has been mined to some extent in the Unaka or Smoky Mountains, eleven miles from the town of Greenville.

Newport.—Manganese has been found near Newport, Cocke county. †

Chilhowee Mountain.—It is reported that manganese exists on Chilhowee Mountain, but the quantity is not yet known. ‡

Morristown.—Manganese ore occurs in a red residual clay at several points about two miles southeast of Morristown in Hamblin county.

Whitfield.—Small quantities of manganese, as already stated, were mined near Whitfield, Hickman county, as early as 1837, and it has also been occasionally mined on a small scale since that time for use in coloring crockery.§

* Resources of Tennessee, J. B. Killebrew assisted by J. M. Safford, 1874, pages 268 and 499.

† Mineral Resources of the United States, 1888, p. 131.

‡ Ibid., 1886, p. 194.

§ Ibid., 1885, pages 344-345.

THE MANGANESE DEPOSITS OF GEORGIA.—*Location and general features.*

The manganese region of Georgia is situated in the northwestern corner of the state, and has its largest development in Bartow county, with smaller areas in Polk, Floyd, Whitfield, and other counties. This region is comprised in the southwesterly extension of the mountains already described in Virginia and Tennessee.

Manganese ores occur in two or possibly more geologic horizons in the Paleozoic rocks of northwest Georgia: one in association with shales and sandstone; the other with cherts or cherty limestones. The age of the sandstone horizon is as yet in some doubt. Dr. C. W. Hayes, of the United States Geological Survey, who has pursued detailed investigations in this state for several years, has kindly furnished the Survey the information that the sandstone has not yet been sufficiently studied to correlate it, and that it may be Cambrian or may be Upper Silurian. (See pages 376-379.) The same authority places the chert referred to above in the Knox dolomite (Safford), the lowest division of the Silurian in the state. Immediately below the chert, in some places, is a gray limestone representing the upper member of the Cambrian.

The sandstone ore belt is well developed in Bartow county. It lies north and northeast of the town of Cartersville and is known as the "Cartersville region;" or as the "Etowah region," from the neighboring Etowah River. It has produced almost all the manganese ore mined in the state. The chert or cherty limestone belt is developed to the west of the Cartersville region in the northern part of Polk county and southern part of Floyd, and thence north in Bartow and Whitfield counties. In its southern part this area is known as the "Cave Spring region."

The two areas are separated from each other by a profound fault passing almost north and south through Cartersville, and and described by C. W. Hayes* as the "Cartersville thrust fault." The deposits of the Cartersville region occur with shales

* The Overthrust Faults of the Southern Appalachians, Geol. Soc. America, Vol. II., 1891, pages 144-154.

and sandstones to the east of the fault; the deposits of the Cave Spring region occur with cherts and cherty limestones to the west. The latter area is comprised within a broad syncline, described by Dr. Hayes as extending from the Tennessee-Georgia line south and southwest through the northwest corner of the latter state. The syncline is bordered on the east by the Cartersville fault, and on the west by another fault, passing through the town of Rome, and described by Hayes as the "Rome thrust fault." Within this syncline are most of those manganese deposits that occur in the Knox dolomite, though some in Catoosa county occur to the west of it.

Both the Cartersville and the Cave Spring regions, as well the areas related to the latter, resemble each other in the association of manganese with brown hematite, and in the general character of the ores themselves. The manganese ores of the Cave Spring region, however, are more scattered, and, so far as has yet been discovered, are in smaller quantities than in the Cartersville region.

THE MANGANESE DEPOSITS OF GEORGIA.—*Cartersville region.*

Production.—The accompanying table gives the production of manganese ores in the Cartersville region from the time they were first mined in 1866 up to 1888:*

Production of manganese ores in the Cartersville region, 1866-1888

	Long tons.
1866†	550
1867	
1868	
1869	
1870	5,000
1871	
1872	
1873	
1874	2,400
1875	2,400
1876	2,400
1877	2,400
1878	2,400
1879	2,400
1880	1,800
1881	1,200
1882	1,000
1883	———
1884	———
1885	2,580
1886	5,981
1887	9,024
1888	5,568

* Mineral Resources of the United States, 1888, p. 127.

† Though small quantities of ore were shipped in 1866 the first active mining is said to have been in 1867.

The Dobbins mine.—The Dobbins mine is in Bartow county, Georgia, five miles north-by-east from the town of Cartersville. It was opened in 1867, and is the oldest manganese mine in the state of Georgia. It was later acquired by the Bartow Manganese Mining and Manufacturing Company, and in 1885 it was leased by E. H. Woodward. From 1867 to 1885 inclusive, 5,500 tons of ore are said to have been mined.* E. H. Woodward shipped 726 tons in 1886.†

The ores are mostly massive with smaller quantities of crystalline ore, and are found in the form of nodules, pockets, and lenticular beds, in a stiff red, brown, or chrome-colored clay. The property comprises part of a hill rising about a hundred and fifty feet above the surrounding level, and running in a general east and west direction. A large part of the hill is composed of the clay that has resulted from the decay, in situ, of the rock which formerly existed in the same position. In some places the clay still shows the original stratification of the rock, and dips vertically or almost so, striking in a direction varying from east and west to northeast and southwest. The ore follows these directions in a general way, though sometimes off-shoots run across the stratification and ramify in various directions. These, however, are probably due to secondary chemical agencies which have dissolved and redeposited the mineral during the transformation of the original bed into its present form. The accompanying figures taken from the side of a pit represent the mode of occurrence of the ore. The bodies of ore vary from a few inches to over five feet in width and alternately thin out and come in again. Frequently the ore occurs in nests of nodules more or less closely assembled in the clay, as shown in the right-hand side of the lower figure.

The bodies of ore often contain pockets of clay or masses of undecomposed rock, the latter blending into the clay or sandy clay, and yet retaining the structure of the original rock. As shown in the figures large masses of sandstone, quartzite, or shaly sandstone, sometimes five feet or

* Mineral Resources of the United States, 1885, p. 330.
† Ibid., 1886, p. 187.

more in diameter, also occur in the clay. They often contain seams and nodules of manganese ore, and represent undecomposed fragments of the original bed that once comprised the whole hill. A common form of these fragments is a fine grained, compact rock of a brown color, glittering

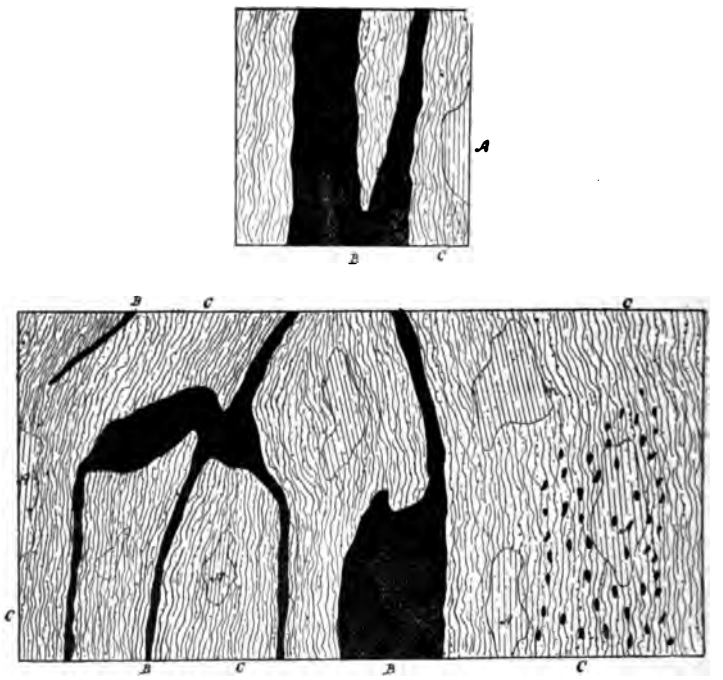

Figure 30. *Sections in a pit at the Dobbins mine, Georgia, showing the occurrence of manganese ore in the residual clay.*

A. Undecayed masses of rock.
B. Manganese ore.
C. Residual clay.
Horizontal and vertical scale: 1 inch=10 feet.

with quartz crystals, or of a massive, cherty nature. A low "reef" of comparatively coarse sandstone, about fifteen feet wide, runs along the crest of the hill in the direction of the strike of the clay. Its outcrop is marked by broken, rocky fragments strongly contrasting with the surrounding clay covered slopes. It probably represents a more resistant stratum which has withstood decomposition.

The Laughorn mine.—The Laughorn mine is in Bartow

county, Georgia, two miles north-by-east from Cartersville. It is operated by Mr. E. H. Woodward and several small pits have been opened.

The manganese is a massive, black, honeycombed, and stalactitic ore with some crystalline pyrolusite, and occurs in much the same manner as at the Dobbins mine. The principal difference is that the ore-bearing clay dips at an angle of about 45° northwest, instead of almost vertically, and lies on the slope of a solid sandstone hill. Fragments of hard quartzite containing concretionary masses of manganese ore are sometimes found in the clay.

The Layton mine.—The Layton mine is in Bartow county, Georgia, two miles north-by-east from Cartersville, and almost adjoins the Laughorn mine. It was formerly worked on a small scale for iron ore, and has lately been opened for manganese.

The manganese occurs as a porous, honeycombed, stalactitic, massive ore, in the form of nodules and lenticular layers, from six inches to three feet in thickness, imbedded in clay. The clay in the neighborhood of the ore bodies often has a black color, due to a stain of manganese, and contains masses of rock in all stages of decomposition. This deposit overlies a bed of brown hematite three feet thick, which in turn lies directly on the solid sandstone.

Figure 31 shows the mode of occurrence of the deposits. The black lines running off from the ore bed on the right hand side of the figure are "stringers" and thin seams of ore penetrating into the sandstone. Between the iron ore bed and the clay is a layer of manganese ore varying from a few inches to three feet in thickness, and forming an almost continuous stratum from the surface down to a depth of fifteen feet, which is as far as it has been followed. The manganese ore alternately encroaches on, and recedes from the iron ore, and is very uncertain in thickness.

A short distance to the west of the pit the iron ore bed becomes much larger, and, though it has not been stripped, it is probably 20 feet or more in thickness. The manganese does not

appear to follow it continuously in this direction and probably represents only a local deposit in it at the place described.

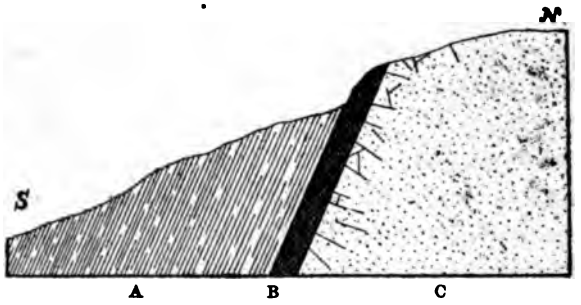

Figure 31. *Section through the Layton mine, Georgia, showing the mode of occurrence of the iron and manganese deposit.*

A. Manganese-bearing clay containing ore in nodules and layers.
B. Iron and manganese ore stratum.
C. Sandstone.
Horizontal and vertical scale: 1 inch=50 feet.

The Bishop mine.—The Bishop mine is in Bartow county, six miles northeast of Cartersville, and belongs to the Dade Coal Company. Several pits have been sunk, but the property was not being worked when visited in October, 1889, and the old openings were mostly caved in, making it difficult to see the exact nature of the deposit.

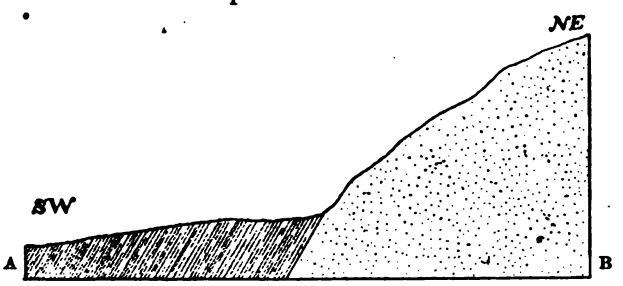

Figure 32. *Section through the Bishop mine, Georgia, showing the mode of occurrence of the manganese-bearing clay.*

A. Manganese-bearing clay.
B. Sandstone.
Horizontal scale: 1 inch=300 feet. Vertical scale: 1 inch=60 feet.

The manganese is in the form of concretionary nodules very much like those described on the Matthews tract at Buena Vista, Virginia. (See page 407). It occurs in clay at the foot of a sandstone hill which rises from seventy-five to a hundred feet

above the surface of the ore-bearing bed. The clay is generally of a chocolate, red, or yellow color, though it is sometimes of a pure snow white with grains of coarse, transparent sand. The accompanying figure shows the mode of occurrence of the ore-bearing deposit.

The Poorhouse mine.—The Poorhouse mine is in Bartow county, twelve miles northeast of Cartersville, and has been worked to a small extent, but is at present not being operated.

Manganese is found here in masses in a black manganiferous clay which is interbedded in layers, from six inches to four feet in thickness, with a yellowish brown or red clay. The whole deposit is interbedded in the sandstone and crops out at the foot of a hill of that rock, which rises about 400 feet above the surrounding drainage. The rocks dip steeply to the southeast and the clay follows them in all their disturbances. This property is one of the clearest examples seen in the region of the derivation of the ore-bearing clay from the decomposition of a rock stratum which once contained the ore in the same form as it now exists in the clay.

The Chumler Hill mine —The Chumler Hill mine is situated in Bartow county, eight miles northeast of Cartersville. It has been worked for many years, but most of the ore is at present obtained from one shaft something over eighty feet deep. The ore was formerly mined in large open pits.

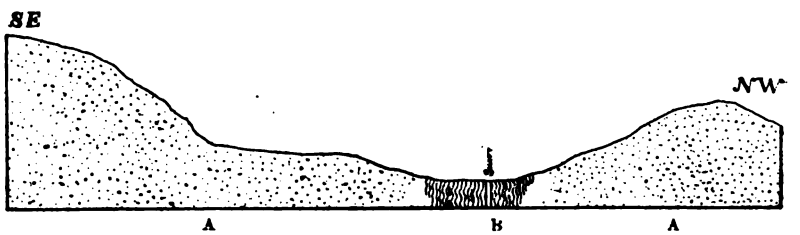

Figure 33. *Northwest-southeast section through the Chumler Hill mine, Georgia, showing the mode of occurrence of the manganese-bearing clay.*

A. Sandstone.

B. Manganese-bearing clay.

Horizontal scale. 1 inch=¼ mile. Vertical scale: 1 inch=400 feet.

The manganese occurs as concretionary nodules of massive and crystalline ore, imbedded in a red clay, which often contains partly decomposed masses of sandstone. The clay bed

occupies the hollow between two sandstone hills and contains ore in irregularly scattered pockets. The accompanying figure shows the mode of occurrence of the ore-bearing clay.

The Shatterfield mine.—The Shatterfield mine is in Bartow county, three miles north of Cartersville. Several small pits and tunnels have been made, but no considerable work has been done.

The ore is of the usual compact, massive or crystalline variety, and is generally in the form of nodules. The property is situated on the northeast slope of a sandstone ridge, running in a general northwest and southeast direction. The ridge rises about two hundred feet above the surrounding drainage and slopes off on the northeast into a valley about half a mile wide, on the other side of which another parallel ridge of sandstone rises to about the same height. No ore has been found on the ridge to the northeast, but on the slope of the southwest ridge it occurs in the form of nodules irregularly scattered through a yellow and buff colored clay, occasionally associated with a black manganiferous clay.

The clay bed dips with the slope of the hill, and appears to lie on it conformably with the bedding. Fragments and nodules of barite from half an inch to six inches in diameter, occur in the clay immediately above the ore, and are sometimes mixed with the latter. Masses of partly decomposed sandstone and quartzite are also found in the clay.

Cherokee county.—Ores similar to those already described in Bartow county are said to occur also in Cherokee, which borders Bartow on the east; but, so far as has yet been found, they are in smaller quantities.

Fannin county.—Similar ores are also said to have been found in Fannin county, at the northern border of the state, but that region is at present too far from railway transportation to permit any attempt at mining them.

Mt. Airy.—According to information kindly furnished by Dr. J. W. Spencer, State Geologist of Georgia, manganese has been found in the metamorphic rocks near Mt. Airy in northeastern Georgia.

THE MANGANESE DEPOSITS OF GEORGIA.—*Cave Spring region.*

General features.—The Cave Spring region lies between Cedartown and Cave Spring, in the northern part of Polk county and the southern part of Floyd. Deposits of a character similar to those found in this area also occur in the northwestern part of Bartow and in Catoosa and Whitfield counties.

The manganese consists largely of a massive ore with some pyrolusite, and, as in the Cartersville region, occurs with brown hematite in the various forms already described, either in the same or separate deposits. The ores differ from the Cartersville ores, however, in that they are found in association with chert. They are usually imbedded in a red clay resulting from the surface decomposition of the chert, though sometimes they are in place in that rock. Between the two extremes of ore in the clay and ore in the rock there are all gradations, and a common occurrence is a hill composed of massive chert or cherty limestone at the base and becoming more and more decomposed above, until at the summit it has been completely converted into a residual clay containing fragments of the original chert bed. The chert fragments vary greatly in size, from a few inches to several feet in diameter, and are in all stages of decomposition, from the original hard, flinty rock to a porous, earthy mass.

The manganese ore exists in much the same form in both the chert and the clay, occurring as nodules, pockets, or lenticular layers, following the general direction of the bedding of the strata. The hematite occurs in the same way except that it is in much larger quantities, and has a stronger tendency to a bedded form, and a lesser tendency to a nodular form. Both ores frequently exist in innumerable thin seams, piercing the rock in all directions, and giving it a brecciated appearance. In such cases the ore is often composed of both iron and manganese, the one blending into the other. Both of the ores are very irregularly distributed, in some places being wanting altogether and in others occurring at short intervals over considerable areas.

The chert is usually a white or gray rock, sometimes brown and rarely black, though it is frequently incrusted

with a black film of oxide of manganese. It is underlain by a large bed of massive, blue-gray limestone, sometimes semi-crystalline and frequently having an colitic structure, a similar structure being often observable in the chert. At Cave Spring the limestone, according to information kindly furnished the Survey by C. W. Hayes, of the United States Geological Survey, represents the upper member of the Cambrian rocks of this region, while the chert, as stated on page 380, corresponds to the Knox dolomite (Safford) .The stratigraphic relation of the chert and limestone is excellently illustrated in the hills to the southeast of the town: the rocks dip to the southeast, the limestone forming the lower parts of the hills and the chert the upper parts. The name of the town is taken from a large spring that issues from the limestone at the foot of the hills.

The Barnsley tract.—The Barnsley tract is in Bartow county, seventeen miles northwest of Cartersville. Several small pits have been sunk and forty-five or fifty tons of ore are said to have been mined.

The manganese is a porous, honeycombed, or stalactitic variety, sometimes containing cavities lined with crystalline ore. It contains inclusions of red clay, and frequently occurs as a cement binding together angular fragments of partly decomposed chert. The ore is found in loose masses irregularly distributed through a red or black clay, which contains numerous fragments of chert in various stages of decomposition. A small pit has been sunk thirty feet into the bed.

On the northeast slope of the hill a dark grayish-blue limestone, underlain by shale, dips westward and passes under the chert. The true contact of the limestone with the ore-bearing chert cannot be seen, as the whole of the upper part of the hill is covered by loose chert fragments which have rolled down and hidden everything until the limestone outcrop is reached. It seems probable, however, that the chert and ore-bearing clay were once parts of a cherty limestone, sometimes consisting largely of chert, at other

times of interbedded chert and limestone; that subsequently the carbonate of lime was leached out and the chert decomposed, leaving a residual clay containing the manganese ore and the chert fragments that have survived decay. The accompanying figure shows the relation of the rocks on this property. The shaft on the summit of the hill on the left side of the figure is the one referred to above.

Figure 34. *Section through the Barnsley tract, Georgia, showing the manganese-bearing chert bed.*

A. Chert and cherty limestone.
B. Limestone.
C. Shale.
Horizontal scale: 1 inch—500 feet. Vertical scale: 1 inch—200 feet.

The William Doherty tract.—The William Doherty tract is in Polk county, two miles south of Cave Spring. Several small pits have been made, and some ore has been shipped. The manganese is generally in the form of nodules, from one inch to two feet in diameter, often containing thin veins of quartz, and associated with brown hematite, either in the same deposit or separately. Occasionally nodules are found with massive brown hematite on the outside and manganese ore on the inside. Both ores are imbedded in a red clay containing many fragments of chert in various stages of decomposition. The masses of ore are either irregularly distributed through this deposit, or are in lenticular beds from one to two feet in thickness and of limited lateral extent. The ore is sometimes in place in the chert; and the deposit, as it now exists, is the remains of a once continuous ore-bearing chert.

The hills containing the ore are low, rounded, and covered by angular chert fragments, so that no continuous ledge of rock is seen. Half a mile to the north, however,

the chert crops out in place on the slope of a ridge running in a general northeast and southwest direction, and dips at about 25° to 35° to the southeast. The chert shows an irregularly decomposed surface with deep channels running in along the lines of bedding. It composes the whole of the ridge, and the edges of the strata are well exposed on the slope. They are frequently impregnated with iron, and in several places manganese is seen in small quantities cutting the chert in a network of small layers and nests, from a sixteenth to a half inch in thickness. Larger quantities of ore are found on the summit, and here the chert has been decomposed for a depth, in some places, of thirty or forty feet, or more. Figure 35 shows the relation of the decayed and undecayed chert on this ridge. Several pits have been opened on the ridge, among which are those described below.

Figure 35. *Section near the William Doherty tract, Georgia, showing the surface decay of the manganese-bearing chert bed.*

A. Decayed chert.

B. Undecayed chert.

Horizontal scale: 1 inch=500 feet. Vertical scale: 1 inch=250 feet.

The Nancy Banks tract.—The Nancy Banks tract is on the line of Polk and Floyd counties, and on the summit of the ridge just described. A pit about twenty feet deep has been sunk and three hundred tons of manganese ore are said to have been mined. The ore occurs in a red clay with numerous fragments of the original chert bed, which have so far withstood decomposition.

The Lewis Ware tract.—The Lewis Ware tract is in Floyd county, about half a mile northeast of the Nancy Banks tract and on the same ridge. Several small pits have been sunk and small quantities of ore have been taken out. The ore is of the

same variety, and occurs in nodules and masses in the clay in the same manner as at the Banks place. The accompanying figure represents the side of a pit thirty-four feet deep, and shows the association of ore-bearing clay and the chert fragments. The so-called "reef" of chert seen running across the figure in large disconnected masses, represents the decomposing remains of a stratum, which, probably being more resistant than the strata immediately above and below it, has survived decay.

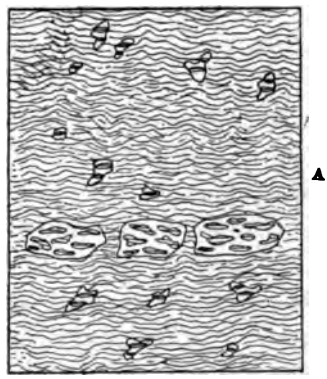

Figure 36. *Section in a pit on the Lewis Ware tract, Georgia, showing the residual manganese-bearing clay which has resulted from the decay of the chert bed.*

A. Manganese-bearing clay. The masses of rock represent parts of the chert bed that have so far escaped decay.

Horizontal and vertical scale. 1 inch=18 feet.

The Hancock tract.—The Hancock tract is in Floyd county, one mile east of Cave Spring. A number of small prospecting pits have been opened on the property and ore has been found in several of them.

The manganese generally occurs in place in the chert, though the latter is much broken by surface weathering and the cracks are filled with red clay. In one place a pit has exposed a pocket of ore from one foot to one and a half feet in thickness, overlain by the broken chert bed. The latter is cut up by a network of thin seams of manganese ore and brown hematite, giving the rock a brecciated appearance. The chert frequently has a granular structure like that of oolitic limestone.

From this property west to Cave Spring, nodules of manganese ore are seen at numerous places in the gullies and along

the creeks. They are all in associations, or have come from associations similar to those just described.

The Tunnel Hill mine.—The Tunnel Hill mine is near the dividing line of Catoosa and Whitfield counties, the property being partly in one and partly in the other. The mine is about a mile from Tunnel Hill station on the Western and Atlantic Railroad. It is owned by the Catoosa Mining and Manufacturing Company, which began work on it in 1889.

The ore occurs generally as botryoidal and kidney-shaped nodules, from one inch to eighteen inches in diameter, often composed of a crystalline interior enclosed by a massive, hard, black crust. It is associated with a red clay containing large masses of chert similar to that at the localities already described in the neighborhood of Cave Spring. The chert, however, is more decomposed than in most of those localities, and there is, therefore, a larger quantity of residual clay and a smaller quantity of cherty fragments. The property is situated on a ridge running in a general direction of north-northeast and rising from a hundred to a hundred and fifty feet above the surrounding drainage. The chert composing the ridge has decayed to a considerable depth, and a shaft was sunk a hundred and fifty feet in it without reaching solid rock.

Both the manganese and brown hematite occur in numerous places on this hill, though the iron, as is usual, is the more abundant, and occurs in pockets and lenticular layers from ten to twenty feet in thickness. The nodules of manganese ore are either scattered throughout the clay or are more or less closely assembled in pockets. In one of the shafts, a number of nodules are seen studding the clay for a depth of twenty feet, and a breadth of three feet. In some places the iron and manganese ores are intimately associated as manganiferous iron ore, in others they occur as distinct masses in the same deposit, often coming in contact or coating each other; and still again they occur in separate deposits, comparatively free from any admixture with each other.

In a pit at the base of the hill, manganese ore occurs in place in the rock, which is often of a characteristic brownish-

chrome color, is hard, and has a conchoidal fracture. The ore is found in it in layers or nests, and frequently the rock is studded with numerous small black, concretions of ore the size of mustard seed. In some places the nodules have weathered out of the rock and lie in the clay on its partly decomposed surface.

THE MANGANESE DEPOSITS OF ALABAMA.

Manganese has been found in several places in Alabama, but it has not been worked to any considerable extent, and only very small quantities have been shipped. It has been found at Stocks' Mills in Cherokee county,* and small quantities have been mined. It also occurs in Chilton, Talladega, Randolph, Calhoun, Cleburne, Etowah, Shelby, and other counties, but in most places it is said to be in small quantities. At Woodstock, in Bibb county, and elsewhere in the state, manganese has been found in the form of manganiferous iron ore. The following analyses cited by E. J. Schmitz show the composition of some of the ores.†

Analyses of manganese ores from Alabama.‡

Variety.	Formation	County.	Analyst.	Peroxide of Manganese.	Metallic Manganese.	Specific Gravity.
Pyrolusite	Metamorphic.	Chilton.	Endemann.	71.220	45.004	.....
Psilomelane	Silurian.	Talladega.	Mallet.	62.430	39.449	3.712
Psilomelane	Metamorphic.	Randolph.	Mallet.	63.250	39.968	3.968

* Mineral Resources of the United States, 1866, p. 183.

† In the table of analyses the column for metallic manganese has been inserted by the writer. It was calculated from the percentage of peroxide given by Mr. Schmitz, and as it is not impossible that certain quantities of other oxides of manganese may have been present in the ore, the percentages of metallic manganese may possibly be too low.

‡ E. J. Schmitz, Trans. Amer. Inst. Mng. Eng., Vol. XII., 1883-84, p. 172.

CHAPTER XVI.

THE MANGANESE DEPOSITS OF TEXAS.

LOCATION OF THE DEPOSITS.

The manganese ores of Texas occur in the central part of the state, mostly in Mason, Llano, and San Saba counties. The different deposits are from forty to sixty miles from railway transportation and no ore has yet been shipped from any of them. Several places, however, have been prospected, especially the Spiller mine and the Kothmann tract in Mason county, and, to a lesser degree, Horse Mountain in Llano county.

THE GEOLOGIC RELATIONS OF THE MANGANESE DEPOSITS.

The ores are associated with quartzites and gneisses, though micaceous and garnetiferous schists are frequently found in the neighborhood. The rocks are much disturbed and dip at various angles, sometimes standing vertically. They are supposed to be of pre-Cambrian age.*

The Paleozoic and Cretaceous rocks border this region on all sides, and areas of them frequently protrude far into, or cap hills of the crystalline rocks.

THE MANGANESE ORES.

Mineralogical forms of the ores.—The manganese minerals

* For further details see C. D. Walcott, Notes on Paleozoic Rocks of Central Texas Amer. Jour. Sci., Vol. XXVIII., 1884, pp. 431-433.

C. D. Walcott, Second Contributions to the Studies on the Cambrian Faunas of North America, Bull. 30, U. S. Geol. Survey, 1886, pp. 57-64.

Theo. B. Comstock, Preliminary Report on the Geology of the Central Mineral Region of Texas, First Annual Report, Geological Survey of Texas, E. T. Dumble, State Geologist, 1889, pp. 241-391.

of the central Texas region occur in the forms of oxides and silicates. The latter, so far as yet determined, generally represent manganiferous varieties of garnet, though the protoxide silicate of manganese known as tephroite has also been found.

The oxides of manganese.—The oxides of manganese occur in either a massive form or as a granular crystalline aggregate, the two being more or less intimately associated. The massive variety has a black color, a smooth conchoidal fracture, and a hardness of 6 to 7. The crystalline variety is black and often very soft, in which condition it represents pyrolusite. The oxides are generally associated with more or less silica, which sometimes amounts to from 15 to 25 per cent, and makes the true mineralogical nature of the ores doubtful. Dr. T. B. Comstock* notes the existence of psilomelane, pyrolusite, and wad in the central Texas region.

Silicates of manganese.—Four varieties of manganese-bearing silicates from central Texas have been analyzed and are described below. These include three forms of manganese garnet, and a specimen of tephroite.

(1) Manganese-alumina-garnet, spessartite.—Specimen from Horse Mountain, Llano county, Texas. This mineral is massive to crystalline; color pale lemon-yellow; streak light yellow; lustre resinous (dull in weathered specimens); translucent; fracture conchoidal to uneven; hardness 7. Its specific gravity as determined by R. N. Brackett is 3.79. It contains disseminated particles of magnetite, and pockets and veins of transparent or smoky quartz. The mineral fuses to a black glass; is insoluble in hydrochloric acid in the fresh state, but after fusion rapidly decomposes with the separation of silica; with fluxes it gives manganese reactions.

The Survey is indebted to the kindness of Professor F. W. Clarke, Chief Chemist of the U. S. Geological Survey, for the following analysis by Dr. W. H. Melville, whose examination has shown the mineral to be spessartite:

* Preliminary Report on the Geology of the Central Mineral Region of Texas, First Annual Report, Geological Survey of Texas, E. T. Dumble, State Geologist, 1889, p. 346.

Analysis of spessartite from Llano county, Texas.

	Per cent.	Ratio.		
Silica ($Si O_2$)	35.93	.600		3.00
Ferric oxide ($Fe_2 O_3$)	4.60	.029	.206	1.03
Alumina ($Al_2 O_3$)	18.06	.177		
Manganese protoxide (MnO)	31.77	.449	.618	3.09
Lime (CaO)	8.48	.162		
Baryta (BaO)	trace			
Magnesia (MgO)	0.69	.017		
Potash (K_2O) / Soda (Na_2O)	0.17			
Phosphoric acid ($P_2 O_5$)	none			
Titantic acid (TiO_2)	trace			
Loss at 105°	0.03			
Loss on ignition	0.36			
	100.11			

In the sample taken for analysis the quartz was separated from the spessartite and the small amount of magnetite was removed by a magnet. "A black oxide of manganese remained in the material analyzed, so that the quantity of ferrous oxide could not be determined. The iron was weighed as ferric oxide."

Supposing all the iron to have been in the ferric state, the ratio of RO, R_2O_3, and SiO_2 as calculated above is very close to the normal garnet ratio 3 : 1 : 3, and shows an almost theoretically pure material. If the iron was in the ferrous form, as it usually is in spessartite, the ratio would be slightly different, but not materially changed from its resemblance to that of garnet.

The ore exists as interbedded layers or lenticular pockets, becoming alternately thick and thin. It is often much jointed and can be picked out of the weathered surface in angular blocks. It is sometimes found finely disseminated in grains through the country gneiss; and in one place, near the foot of Horse Mountain, what appears to be the same mineral occurs as inclusions in a magnetic iron ore.

(2) Calcium-iron-garnet, andradite.—Two specimens of this variety of garnet from the Kothmann tract, fifteen miles northeast of the town of Mason, Mason county, have been

analyzed. Both specimens are impure, as is shown by their physical features and by their variation from the true garnet ratio, but they probably approach the latter closely enough to be classified as garnets. It has been suggested by Dr. S. L. Penfield, who has kindly examined these analyses, that the minerals represent manganese varieties of andradite, which is a calcium-iron-garnet having the formula $Ca_3Fe_2Si_3O_{12}$, and that they bear a resemblance to the variety from Franklin, New Jersey, called polyadelphite by Thomson. The analysis of polyadelphite is given below after the analyses of the Texas specimens. In the latter it will be observed that manganese replaces a larger part of the lime of the ordinary andradite.

The following analyses of the Texas specimens, made by R. N. Brackett, were not intended to be complete, but they show the important constituents of the minerals. They were made of material dried at 110°-115° Centigrade.

(*a*) This is a massive or semi-crystalline mineral; color chocolate-brown; streak light brown; lustre resinous; translucent; fracture uneven; hardness 7-7.5; specific gravity 3.57. The mineral fuses readily into a black glass; is only slightly attacked by hydrochloric acid in the fresh state, but is readily decomposed with the separation of silica after fusion; with fluxes it gives manganese reactions.

Analysis of andradite from Mason county, Texas.

	Per cent.	Ratio.		
Silica (SiO_2)	37.24	.621		3.15
Ferric oxide (Fe_2O_3)	31.17	.195		.98
Alumina (Al_2O_3)	trace			
Manganese protoxide (MnO)	20.11	.283		
Lime (CaO)	10.16	.181	.497	2.49
Difference (magnesia?)	1.32	.033		
	100.00			

It will be observed that though the RO is low, the ratio of RO, R_2O_3, and SiO_2 approaches the garnet ratio 3 : 1 : 3.

(*b*) This is a crystalline mineral; color deep yellow; lustre resinous to vitreous; translucent; fracture uneven; hard-

ness 6; specific gravity 3.72. The mineral fuses readily into a black glass; is only slightly attacked by hydrochloric acid in the fresh state, but after fusion readily decomposes with the separation of silica; with fluxes it gives manganese reactions.

Analysis of andradite from Mason county, Texas.

	Per cent.	Ratio.		
Silica (SiO_2)	36.24	0.605		3.02
Ferric oxide (Fe_2O_3)	15.91	0.100	210	1.05
Alumina (Al_2O_3)	11.23	0.110		
Manganese protoxide (MnO)	30.72	0.434		
Lime (CaO)	2.04	0.037	527	2.63
Magnesia (MgO)	2.22	0.056		
Difference (alkalies ?)	1.64			
	100.00			

The ratio of RO, R_2O_3, and SiO_2 in the above analysis approaches the usual garnet ratio of 3 : 1 : 3. The RO is low, but not so far from the theoretical ratio as in the last analysis.

(*c*) The resemblance of the two Texas specimens of andradite, of which analyses have been given, to the variety known as polyadelphite, is seen in the following analysis of of the latter mineral by Thomson. It will be observed that both the Texas specimens contain more manganese protoxide and proportionally less lime than polyadelphite.

*Analysis of polyadelphite from Franklin, New Jersey.**

Silica (SiO_2)	33.72
Ferric oxide (Fe_2O_3)	17.64
Alumina (Al_2O_3)	7.97
Manganese protoxide (MnO)	16.70
Lime (CaO)	25.88
Loss on ignition	0.08
	101.99

(3) Tephroite.—Specimen from the Kothmann tract, Mason county, Texas. This mineral is massive; color gray or greenish-gray; streak white; lustre resinous; translucent;

* Ann. Lyc. N. Y., III., p. 9, 1829.

hardness 6; very tough; specific gravity 3.94. It is fusible, gelatinizes in hydrochloric acid, and with fluxes gives manganese reactions. It effervesces in hydrochloric acid, probably from the presence of a carbonate, as shown in the analysis.

Like the last two minerals, it is much jointed and breaks into angular blocks. It is decomposed on the surface and along the joint cracks, giving rise to a black incrustation of oxide of manganese, enclosing an interior of the unaltered mineral. The following analysis, made by W. A. Noyes, shows its composition:

Analysis of tephroite from Mason county, Texas.

Silica (SiO_2)	28.57
Ferric oxide (Fe_2O_3)	5.52
Alumina (Al_2O_3)	2.46
Manganese protoxide (MnO)	58.86
Lime (CaO)	0.30
Magnesia (MgO)	0.80
Alkalies (as Na_2O)	0.27
Carbonic acid (CO_2)	2.92
	99.70

It is evident from the analysis that the specimen is an impure material, but the composition approaches that of tephroite, which is a protoxide silicate of manganese having the formula $2MnO, SiO_2$, and containing theoretically manganese protoxide 70.2 and silica 29.8 per cent. The sesquioxide of iron and the alumina do not normally belong in a protoxide silicate and are probably admixtures, due to the specimen being a massive material. The carbonic acid possibly exists as carbonate of manganese, which may have been formed by the alteration of the silicate.

Relation of the oxides and silicates of manganese.—The manganese oxides and silicates occur together in the same deposits. The oxides are never found alone, but are invariably associated with a greater or less quantity of the silicates, generally the garnets. An examination of the various deposits shows that these two classes of minerals,

oxides and silicates of manganese, are not only associated, but that, in many places at least, the oxide is the result of the oxidation of the silicate, and is absolutely dependent for its existence on the presence of that mineral. * A study of the analyses given beyond still further confirms this supposition. The silicates are sometimes seen on the surface in an entirely unaltered condition, but they usually show the presence of a greater or less quantity of oxide, either as an incrustation or as black specks studding the partly disintegrated outcrop.

The extent to which the alteration of the silicate has gone on in different places varies considerably, and is regulated by two sets of conditions: (1) the mineralogical nature of the silicate, on which depends its power to resist chemical decomposition; (2) the physical nature of the silicate and the surrounding rocks, such as joint cracks, porosity, etc., on which depends the power of the altering agents, in the forms of air and surface waters containing carbonic or other acids, to reach the interior of the deposit. These conditions, especially the latter, vary greatly in different localities and even in different parts of the same bed. Hence the black oxide often composes almost the whole of the outcrop of the bed in one place, while on either side and on the same outcrop the fresh unaltered silicate is found. The maximum downward extent of this alteration has not been proved by practical test, but generally it is only superficial, though in a few places a partial alteration extends to considerable depths.

In the initial stage of decomposition, the silicate becomes coated with a thin, black film of oxide, or black specks are formed throughout the mass, which grow larger and more numerous as decomposition proceeds. The appearance of a black film is, however, the most common form of initial alteration, and this gradually extends into the deposit along the faces of

* A possible, though not certain exception to this is the Spiller mine, where most of the ore deposit even at a depth is oxide. The oxide here may possibly represent the original condition of the ore and may not have been derived from the silicate, though the latter is associated with it. (See Spiller mine.)

the joint cracks, giving a section of the deposit the appearance of a brown or yellow mass streaked by straight parallel and intersecting lines. The film, as decay goes on, becomes thicker and thicker until it almost entirely replaces the silicate, and a section of the bed has the appearance of a black body studded with irregularly shaped masses of brown or yellow silicate. These grow fewer and smaller in the further stages of decomposition, until they disappear altogether, and the whole bed is converted into a highly siliceous oxide. In the final stage of decomposition the ore is often spotted with small earthy inclusions, probably representing a part of the siliceous remains of the original silicate. When the silicate contains crystals or segregations of quartz or interbedded lenticular strata of the same, similar associations occur in the oxide.

Float ore.—It has been noted by the miners in this region that loose fragments of ore, known as "float ore," of good quality and composed almost entirely of oxide of manganese are frequently found on the surface; yet when they work into the deposit from which these appear to have come, they find it is composed almost entirely of the silicates of manganese. This leads them to believe that they have not found the right deposit, and has been the cause of many a fruitless search for the supposed hidden lead, which, it is unnecessary to say, is rarely found. The float specimens have doubtless come from the deposit of silicate, but they represent fragments of the crust of oxide formed on the surface of that mineral, or else fragments of the original silicate which have broken loose from the main body, have been freely exposed on the hillsides to the altering action of atmospheric influences, and have been completely converted to oxide; while the main deposit, being better protected from these influences, is still mostly in an unaltered state.

Commercial value of the manganese ores.—The oxides are the only ores of manganese in the central Texas region that can at present be used as a source of manganese, as the silicates contain too large a percentage of silica (28 to 37 per

cent) to be applicable, according to present standards, for such purposes. The considerable percentage of lime in some of the silicates, however, might permit their use as admixtures with better ores.

The table of analyses given below represents the commercially important features of the manganese ores of the central Texas region.

Analysis No. 1 was kindly furnished the Survey by Mr. D. M. Barringer of Philadelphia.

Analyses Nos. 2-5 inclusive were made for the owners of the mine, the Wakefield Coal, Iron and Land Improvement Company.

Analyses Nos. 7–10 have already been given in the discussion of the mineralogical nature of the ores, but they are presented here in a different form in order to bring out their commercially important features.

Analyses Nos. 1, 2, 4, and 6 represent the best grades of ore found on the Spiller property. Analysis No. 3 represents the more siliceous ore from the same property.

Analyses of manganese ores from central Texas.

LOCALITY.	Manganese.	Iron.	Silica.	Phosphorus	Lime.	ANALYZED BY
(1) Spiller mine.....	57.87	1.28	5.28	0.012	.....	Booth, Garrett and Blair.
(2) " "	64.60	2.22	10.22	0.012	.....	Davenport Fisher.
(3) " "	48.54	3.30	21.12	0.024	.....	Davenport Fisher.
(4) " "	56.57	1.10	5.85	0.042	.....	Carnegie Bros. & Co.
(5) " "	61.59	.....	.....	0.025	.....	W. J. Rattle.
(6) " "	42.75	.....	9.70	.....	.....	R. N. Brackett.
(7) Kothmann tract	15.57	21.82	37.24	.....	10.16	" " "
(8) " "	23.79	11.14	36.24	.....	2.04	" " "
(9) " "	45.58	3.86	28.57	.....	0.80	W. A. Noyes.
(10) Horse Mountain	24.60	3.22	35.93	none	8.48	W. H. Melville.

The following table quoted from Dr. Comstock's report gives additional analyses of the manganese ores from the Spiller mine:

Analyses of manganese ores from the Spiller mine, Texas. *

Manganese peroxide	.....	1.48	trace	3.06
Manganese sesquioxide	56.63	36.12	....	66.64
Manganese protoxide	.....	.....	29.04	.....
Ferric oxide, Alumina	9.00	7.50	18.35	7.63
Lime	3.05	8.90	9.74	0.73
Magnesia	1.31	trace	trace	trace
Water	.....	.....	.....	3.00
Phosphoric acid	trace	trace	trace	.....
Sulphuric acid	trace	.....	.....	.....
Silica	11.47	46.15	43.10	19.13
Total	100.28	100.15	100.23	100.19
Metallic manganese	51.33	26.07	22.48	48.32
Phosphorus	trace	trace	trace	.....

MODE OF OCCURRENCE OF THE MANGANESE ORES.

Both the oxides and the silicates of manganese occur, so far as observed, as lenticular layers in the quartzites and gneisses. They have not been seen anywhere to cut across the enclosing beds, but, on the contrary, appear to follow the strike of the country rocks throughout their folds. They are not confined to one kind of rock, but have been observed in at least two different associations: at the Spiller mine they are in the quartzite, while at the Kothmann property and on Horse Mountain they are in gneisses. Though the manganese deposits are probably lenticular, alternately thinning out and appearing again beyond, they are often traceable for considerable distances, in some places for half a mile or more. They vary from a few inches to several feet in thickness and crop out along the summits and slopes of the mountains. They frequently contain lenticular strata of a similar nature to the enclosing rocks.

* T. B. Comstock, Preliminary Report on the Geology of the Central Mineral Region of Texas, First Annual Report, Geological Survey of Texas, 1890, E. T. Dumble, State Geologist, p. 346. The analyses were made by Mr. L. Magnenat of the same Survey.

DESCRIPTIONS OF LOCALITIES.

The Spiller mine.—The Spiller mine is in Mason county, fifteen miles northeast of the town of Mason, and is the property of the Wakefield Coal, Iron and Land Improvement Company. It has been prospected by diamond drill borings and small shafts, but no quantity of ore has been shipped and no work is being done at present. The nearest railway point is Burnet in Burnet county, on the Austin and Northwestern Railroad, about sixty miles east-by-south from the property.

The rock enclosing the ore is composed mostly of a hard, bedded quartzite of a white, gray, or light red color. It often contains small quantities of mica and is in places interbedded with micaceous schist and feldspathic rocks. The weathered part of the quartzite assumes a sandy structure and often has the appearance of a fine grained, friable sandstone. Specimens brought up in the diamond drill borings, however, are of a massive, vitreous nature, and no grains of sand are visible. The rocks are much disturbed and strike from north and south to northwest and southeast; they dip from almost horizontally to 45° or more west to southwest.

These rocks form the mass of a hill running in a general north and south direction and rising several hundred feet above the surrounding level. The eastern slope is steep and rugged and the edges of the rocks are exposed in ledges dipping into the hill at sharp angles. The western slope, however, is much more gentle and here the rocks are sometimes almost horizontal. It is on this slope that the manganese has been found, occurring as interbedded lenticular layers in the quartzite. The ore is a hard, steel-gray oxide, blending into a softer, fine grained, crystalline pyrolusite. It is associated with a yellow manganese-bearing silicate which looks like the spessartite (manganese-alumina-garnet) described on page 434, and frequently the silicate is studded with black spots of oxide of manganese. In such cases the silicate has become porous and soft, and shows signs of decay. Most of the bed, however, where exposed, is in the form of oxide, and a number of diamond drill borings prove that

ore to compose almost the whole of the bed even at considerable depths.

The ore bed is exposed at several places and runs parallel to the direction of the hill. The thickest outcrop seen on the surface was three feet of solid ore. Beneath this is a mixture of oxide and the yellow silicate interbedded in thin lenticular sheets with quartzite.

The outcrops of the ore deposit on the surface are not continuous, but are seen at intervals along the slope, separated by areas of quartzite. These isolated exposures, however, appear to occupy the same stratigraphic position in the quartzite, and it is probable that further development of the property will show that the ore deposit is made up of a series of lenticular bodies following this position in the quartzite and varying in thickness and lateral extent.

Two small shafts have been sunk on the property. One was worked several years ago to obtain manganese ore as a source of silver, which is said to be present in small quantities; and the second shaft was sunk by the present owners of the property in prospecting for manganese. About twenty-nine diamond drill borings have been made in prospecting the property and in many of them ore has been found. Analyses of the ore from this property are given on pages 440–441.

The Kothmann tract.—The Kothmann tract is three miles southeast of the Spiller mine and has been prospected by a few small pits, but no extensive work has been done. It is on a ridge rising 260 feet above the surrounding drainage, running in a general north and south direction, and composed mostly of gneisses, with micaceous and garnetiferous schists. The gneisses, however, form the mass of the hill. The rocks strike in the general direction of the hill, and dip vertically or almost so, sometimes inclining a little to the east or west. The manganese occurs in the form of silicates, which exist apparently in lenticular beds in the country rock. The silicates are more or less oxidized and stained black on the surface. Three of these deposits have been found on the hill and one of them is traceable for about half a mile along the slope. They follow, so far

as seen, the same dip and strike as the enclosing rocks and conform to all their disturbances, running in parallel belts at different levels along the west slope of the hill.

The lowermost bed on the hillside is composed of the manganiferous garnet (andradite) described under (*a*), page 435, and frequently contains subordinate veins and pockets of transparent quartz. It varies from two to ten feet in width and is traceable for almost half a mile along the slope of the ridge. It is much jointed and readily breaks into blocks. The surface of the blocks and the faces of all the joint cracks are stained black by the oxidation of the silicate. This decomposition product is in some places simply a film covering the unaltered interior, but in others it extends an inch or more into the silicate and forms a black crust of oxide, either of a light, porous consistency or of a heavier and more massive nature. Frequently the bed is divided longitudinally by subordinate layers of gneiss or schist; and crystals of black mica (biotite) from a half to one inch in diameter are sometimes imbedded in the silicate. The deposit dips vertically, trending locally a little to the east or west, and varying with the condition of disturbance of the enclosing rock.

The manganiferous garnet described under (*b*), page 435, occupies a belt running parallel to this bed, but at an elevation of about fifteen feet higher on the hillside, and about a hundred feet distant on the slope. It is in an impure state and is associated with feldspar, hornblende, and biotite. The garnet is much jointed and the surfaces of the joint cracks are coated with the black oxide in the same way as in the last deposit.

This material is not so continuous as the last and it often runs out altogether, appearing again farther on. Where it disappears its place is taken by quartz, feldspar, etc., occupying the same position as the silicate of manganese occupies elsewhere. In some places, however, the bed seems to thin out altogether and the enclosing gneisses come together, separating again beyond. The silicate of manganese, where found, varies from one to three feet in thickness.

At the southern end of this deposit the tephroite or protoxide silicate of manganese, described on pages 436–437, occurs.

It is three feet in thickness and is much jointed, breaking into blocks which are often blackened and converted into oxide for a distance of two or three inches in from their surfaces; while in some cases only a small kernel of the original silicate remains. The silicate has decayed more extensively here than anywhere else on the hill, but the decomposition is only local and no great amount of oxide occurs.

On the summit of the hill is another outcrop of a silicate of manganese apparently similar to that described under (*a*) on page 435.

Black fragments of oxide of manganese containing a comparatively small quantity of silica are frequently found on the slopes of the hill. They are derived in a manner explained on page 439, from the surface oxidation of loose masses of the silicates already described, and do not point to any large body of ore in the oxide form.

The following analyses represent the composition of the different varieties of manganese minerals from this property. They have already been given in the description of the mineralogical nature of the ores (pages 434–437), but are presented in a different form here to bring out their commercially important features.

*Analyses of manganese ore from the Kothmann tract, Texas.**

	1.	2.	3.
Manganese	15.57	23.79	45.58
Iron	21.82	11.14	3.86
Silica	37.24	36.24	28.57
Phosphorus	.....	.....	.....
Lime	10.16	2.04	0.30

Horse Mountain.—Horse Mountain is in Llano county, five miles north of the town of Llano. Manganese has been found on its eastern slope, on the property of Mr. Griffey. The rocks of the mountain consist of fine grained gneisses, occasionally associated with coarser varieties of the same rock, and cut by veins

* The numbers 1, 2, and 3 of the analyses correspond respectively to Nos. (*a*) and (*b*), on page 435, and No. 3 on page 436.

of transparent or milky quartz. The fine grained gneiss often assumes a shaly structure on the weathered surface. The rocks dip in a general westerly direction at angles varying from 20° to 40°, and strike in a general north and south direction. The manganese-bearing deposit is interbedded with the gneisses and reaches a maximum thickness, where seen, of two feet. It is composed mostly of the yellow manganese-alumina-garnet (spessartite) described on page 433, and is associated with veins and crystals of transparent or smoky quartz, or interbedded with lenticular layers of the same material and of the country gneiss. It also contains disseminated particles of magnetite. The garnet has in some places been mostly altered into an oxide, and in a small stripping made on part of the bed, a thickness of one foot of oxide, associated with thin layers of quartz is exposed. Even where the garnet has not been completely altered, it almost always shows the action of surface oxidation in the small black specks of oxide of manganese on its surface.

The garnet is of irregular distribution, in some places thinning out altogether, and in others reaching a thickness of from one to two feet, or impregnating the gneiss in grains or as a yellow coloring matter. It is traceable at intervals for 400 yards along the eastern slope of the mountain and strikes in the same direction as the enclosing rocks.

On the same slope of the mountain, but lower down and a few hundred feet north of the openings mentioned above, is a small outcrop of a dark brown manganese-bearing silicate apparently similar to the garnet described first at the Kothmann property.

A mineral which resembles the yellow garnet, spessartite, described above, occurs in small quantities in association with magnetic iron ore about half a mile from this locality and near the foot of the mountain.

The following analysis represents the composition of the ore on this property. The analysis is part of that made by Dr. W. H. Melville and already given on page 434 in the discussion

of the mineralogical nature of the ore, but it is presented here in a different form in order to bring out its commercially important features:

Analysis of manganese ore from Horse Mountain, Texas.

Manganese	24.60
Iron	3.22
Silica	35.93
Phosphorus	none
Lime	8.48

CHAPTER XVII.

THE MANGANESE DEPOSITS OF THE ROCKY MOUNTAINS.

LOCATION AND GENERAL FEATURES OF THE DEPOSITS.

Manganiferous silver ores are of frequent occurrence in the Rocky Mountain region from the Canadian border on the north to and beyond the Mexican border on the south, but ores suitable for use as a source of manganese are rare in that region, and, so far, have been found only in Colorado. Manganiferous silver ores are much more valuable for their contents of silver than of manganese, and as they cannot be used as a source of both metals, the more valuable use of course prevails. Such ores, even if they were not consumed for their silver contents, are rarely of such a quality or in sufficient quantities to make them a desirable source of manganese.

Colorado is an exception to this rule and in that state, especially at Leadville, some of the silver-bearing deposits contain a considerable quantity of manganese and manganiferous iron ores, which are used as a source of spiegeleisen and ferromanganese. Elsewhere in the Rocky Mountains, however, though the ores are not used for these purposes, the manganese in them, when in the form of oxide, is valuable as a fluxing material in extracting the silver, and is paid for at the same rate as iron (10 cents per unit) at the various smelting works where silver ores are treated. For this reason, manganiferous silver ores are often mixed with other more refractory silver ores to assist in the process of smelting.

Up to the present time (December, 1890,) the only manganese ores in the Rocky Mountains that have been mined to

any considerable extent as a source of manganese for the manufacture of spiegeleisen or ferro-manganese, or in fact for any purpose other than for use in smelting silver ores, are those of Colorado, especially of the Leadville district. These ores are used by the Colorado Coal and Iron Company of Pueblo, and lately considerable quantities of the same ore are said to have been shipped to Chicago and mostly consumed by the Illinois Steel Company.

In addition to the manganese ores in the silver deposits, considerable quantities of manganese and manganiferous iron ores have been found in several places in Colorado, especially in Gunnison county, and with improved transportation facilities and an increase in the already rapidly growing iron industry of that state, they will probably before many years enter the list as producers of manganese ore.

Besides the purely manganese ores large quantities of manganiferous silver ores have for a number of years been mined in the Rocky Mountains; and in some places manganiferous iron ores are mined for use in fluxing at the various smelters. The most noted localities at which manganiferous silver ores occur are Butte City, Montana; Leadville, Colorado; and Tombstone, Arizona. At Legal Tender Hill, Silver City, New Mexico, a manganiferous iron ore containing about 13 per cent of manganese is said to be mined exclusively for fluxing purposes.

A table of the production and value of manganiferous silver ores mined in the Rocky Mountains from 1885 to 1888 is given on page 68 of this report.

NATURE, MODE OF OCCURRENCE, AND GEOLOGIC RELATIONS OF THE MANGANIFEROUS SILVER ORES.

Manganiferous silver ores are not confined to a contents of manganese and silver alone, but frequently carry various other metals, among which are gold, lead, zinc, antimony, copper, etc. The manganese occurs mostly in the forms of the different oxides or as carbonate (rhodochrosite) and silicate (rhodonite). In some localities, notably at Butte City, Montana, the oxides are met above the water level of the country, and the carbonate and silicate below that.

level, the first having originated from the oxidation of the last two. Besides these forms, other rarer manganese minerals sometimes occur in manganiferous silver ores: the sulphide of manganese (alabandite) occurs at Kingston in New Mexico, and at Potosi in old Mexico. The tungstate of manganese (huebnerite) is found in the Gagnon vein at Butte City, Montana, and in the Mammoth district, Nevada.* In addition to these minerals many others occur, but all except the oxides, the carbonate, and the silicate, are in very small quantities and are mentioned here simply to show the variety of forms under which the metal is found in manganiferous silver ores.

The manganese minerals are associated with the precious and base metals in a gangue of variable character: in some places the gangue is calcareous, in others highly siliceous, and in still others highly ferruginous. In the last case the manganese is often mixed with the iron in the form of a manganiferous iron ore. The manganese minerals form a very different proportion of the vein matter in different places, sometimes amounting to less than one per cent, and sometimes to a large part of the whole mass; in fact, an oxide, carbonate, or silicate of manganese occasionally forms the larger part of the gangue of the other metals.

Manganiferous silver ores usually occur in vein deposits or in the various forms of contact, chamber, and chimney deposits, though, as shown on page 91, stratified manganese deposits frequently contain small quantities of silver.

Manganiferous silver deposits are not confined to any one series of rocks: at Butte City, Montana, they occur in granite; at Leadville, Colorado, they occur mostly at the contact of Lower Carboniferous limestone and eruptive porphyry; at Tombstone, Arizona, they occur with a series of limestones and quartzites, which are said to be of Lower Carboniferous age. In each district they are marked by

*Near Golconda, Nevada, tungsten is found in a bedded deposit of manganese oxide, which does not contain enough silver ore to be classed as a manganiferous silver ore. See description of the Golconda deposit in the next chapter.

certain distinguishing features, not only in mode of occurrence, but in the character of the ore, so that further generalizations cannot be given here, and the reader is referred for details to the descriptions of the different localities given in this chapter.

NATURE AND MODE OF OCCURRENCE OF THE MANGANESE ORES.

The manganese ores of the Rocky Mountains containing no silver and valuable only for their contents of manganese, or of that and any iron that may be present, are, so far as known, confined mostly to Colorado, with smaller quantities in New Mexico and elsewhere. The ores exist as oxides and are often associated with more or less iron in the form of manganiferous iron ore. In Colorado they occur mostly as bedded deposits, or as pockets and nests in stratified rocks, generally limestones. In some places they are in considerable quantities, but with few exceptions, they are too far from railway transportation to be used at present. They are treated more in detail under the head of Cebolla Valley and the other places in Gunnison county, Colorado.

Besides these bedded deposits, manganese has been found in the form of oxides in lava rocks in several parts of Gunnison county. It occurs as pockets, nests, or as the cement of a breccia, usually as a hard, massive, impure, black material, high in silica, variable in phosphorus, and containing small quantities of iron. The ore is probably too small in quantity, and contains too much injurious impurity to be of value. It seems likely that this ore has originated by the oxidation of manganiferous silicates in the lava, and by the subsequent segregation of the manganese in the form of oxide. It is possible for such deposits to occur with any igneous rocks that contain manganiferous silicates. Two localities of such ores are described in this chapter, one in Steuben Valley, the other near Sapinero, both in Gunnison county, Colorado.

THE MANGANIFEROUS SILVER DEPOSITS OF MONTANA.—*Butte City*

General features.—Manganiferous silver ores are found

in greater or less quantities in all the silver-bearing veins of Butte City, Montana. They are not used as a source of manganese for reasons already explained, but the presence of that metal, by reason of its fluxing qualities, gives them a value in addition to that of the silver they contain. Not only are these ores of value in fluxing, but when in the form of oxide, according to Richard Pearce,* they act as oxidizers for the zinc blende which occurs with almost all of the Butte City silver ores.

The country rock at the Butte City mines is a gray granite,† which is divided by Dr. S. F. Emmons‡ into two varieties, the "Butte granite" and "Bluebird granite." The former is described as a "rather dark-colored rock, of moderately coarse but very even grain, consisting of quartz, orthoclase and plagioclase feldspars, and as basic constituents, of which it has an unusually large proportion, of mica, hornblende, and augite." The "Bluebird granite" is described as "a light-colored rock composed almost exclusively of quartz and orthoclase with a very little biotite. * * * In certain transition-specimens a white opaque feldspar can be distinguished from the pinkish orthoclase, which is probably triclinic, and, with the increase in this constituent, the mica increases correspondingly."

Two classes of ore deposits, differing markedly in the character of their metalliferous contents, have been distinguished in this region:

(1) Silver-bearing deposits, always containing manganese associated with quartz, and carrying pyrite, galena, sphalerite, and the other sulphides. Copper is either in small quantities or entirely absent.

(2) Copper-bearing deposits, containing a variable quantity of silver and little or no manganese or sphalerite. The common minerals are chalcocite, chalcopyrite, bornite, enargite, and variable quantities of iron pyrites.

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* Trans. Amer. Inst. Mng. Eng., Vol. XI., 1882-3, p. 59.

† E. D. Peters, Jr., Mineral Resources of the United States, 1883-84, p. 375.
S. F. Emmons, Amer. Inst. Mng. Eng., 1887-88, Vol. XVI., pp. 51-52.
W. P. Blake, Ibid., 1887-88, Vol. XVI., p. 67.

‡ Ibid., pp. 51-52.

It will be seen that while the silver deposits are characterized by the presence of manganese, the copper deposits are characterized by an entire or almost entire absence of it. Both classes of deposits occur in the same neighborhood, but are grouped together separately, the silver veins lying to the west and north, and the copper veins lying to the east and south.

In the silver deposits, the manganese near the surface, and generally down to the water level of the country, is in the form of the various oxides. E. D. Peters, Jr.,* states that it occurs as pyrolusite, psilomelane, braunite, and wad, named in the order of their abundance, the wad being comparatively rare. The percentage of silver varies greatly and is usually largest when the manganese is in small quantities, and least when that material forms the bulk of the ore (Peters.) When manganese is in small quantities its place is commonly filled by quartz. In the oxidized parts of the deposits, above the water level, the gangue is blackened by the oxides of manganese which obscure the other constituents; but below that level, surface influences have not affected the gangue, and the different minerals occur in their original unoxidized condition. The blackened quartz gangue is replaced by pure white or transparent quartz, associated with pink silicate of manganese (rhodonite) and carbonate of manganese (rhodochrosite). In this gangue are found crystals, nests, and ramifying veins of the sulphides: sphalerite, pyrite, chalcopyrite, and galena, the last two occurring in limited quantities, and all of them forming from less than 3 per cent to rarely over 5 per cent of the gangue rock.† Quartz usually forms the larger part of the gangue, though the mixture of silicate and carbonate of manganese, called by the miners "pink manganese," forms an appreciable percentage, and, in some places, though rarely, comprises most of the gangue. Such ores occur in the Lexington, Moulton, Alice, Magna Charta and many other mines on the Rainbow and other lodes.

The following analyses quoted from Mr. Peters, repre-

* Mineral Resources of the United States, 1883-84, p. 379.

† E. D. Peters, Jr., Ibid., p. 380.

sent the composition of three samples of manganiferous silver ores from the Butte City region.

*Analyses of manganiferous silver ores from Butte City, Montana.**

Manganese oxides...	88.40	47.60	21.000
Iron oxides.....	3.20	12.40	7.700
Silica.....	6.60	34.20	66.400
Alumina.....	.....	3.70	2.400
Silver.....	0.03	0.11	0.275
	(9 ounces)	(32 ounces)	(80 ounces)
Sulphur.....	.....	trace	.....
Moisture and loss...	1.77	1.99	2.225
	100.00	100.00	100.00

These analyses show, as explained by Mr. Peters, the increase of the quantity of silver with the decrease of manganese.

The Rainbow lode.—In the Rainbow lode, according to Professor William P. Blake,† the oxidation has extended downward for a depth of from 150 to 200 feet, and the vein rock is rusty from iron or black from manganese. Below that level, however the undecomposed sulphides of iron, zinc, lead, and silver are found associated in a gangue of quartz and carbonate of manganese. Metallic silver, in the form of wire-silver or thin films, is found not only in the vein rock but also in the granite "horses" in the vein. Gold also forms one of the constituents of the vein.

The carbonate of manganese is the most characteristic mineral in the lode, and it occurs in both the massive and crystalline forms. When freshly mined it has a clear rose color, which it loses on exposure. Quartz is usually associated with it in greater or less quantities, in some places as a network of thin veins containing variable quantities of metalliferous sulphides, in others as finely disseminated material, giving the rhodochrosite an abnormal hardness. Rhodochrosite is found not only in the main lode, but in the many small feeders that run into it and ramify through the granite in the neighborhood of the main de-

* E. D. Peters, Jr., Mineral Resources of the United States, 1883-4. pp. 379-380.

† Amer. Inst. Mng. Eng., XVI., 1887-88, pp. 74-75.

posit. In such cases, of frequent occurrence are thin veins lined on both sides with quartz and filled on the inside with rhodochrosite. Sometimes the quartz is wanting, and the rhodochrosite comes in direct contact with the country granite; while at other times rhodochrosite is wanting, and quartz fills the whole cavity. The main lode, however, may be said, according to Professor Blake, to consist of quartz with a central filling of carbonate of manganese and ore.

The following sections by Professor Blake,* made across the vein at different levels in the Alice mine, which is on this lode, will give an idea not only of the mode of occurrence of the manganese, but also of the relation of the oxidized and the unaltered parts of the vein.

Cross sections of the Rainbow lode at the Alice mine.

	Feet.
On level I., 100 feet from the surface:	
"i. Granite of southwest wall	....
"ii. Clay wall	....
"iii. Quartz-vein stuff shattered and broken	27
"iv. " " " first class milling ore	12
"v. " " " black with oxide manganese (poor)	12
"vi. " " " 'hard ledge'	9
"vii. Granite, northwest wall, country rock	....
	60
On level II., 209 feet from the surface:	
"i. Clay wall mixed with quartz	2
"ii. Black pyritous ore of high grade	1
"iii. Granite horse	2
"iv. Broken and shattered quartz, low grade ore with seams and nodular masses of manganese spar	30
"v. Clay wall	....
"vi. Coarse broken quartz, second and third class ore	12
"vii. Clay wall	....
"viii. Hard quartz ore with veins of manganese spar, first and second class ore, good in stopes above	28
"ix. Granite of northwest wall, country rock	....
	75
On level III.:	
"i. Granite of southeast wall at shaft, with heavy clay wall mixed with quartz	....
"ii. Flinty qartz	11
"iii. Crushed vein-stone, rounded and irregular fragments	29
Clay seam	....
"iv. Second class ore with granite horse	8
"v. Black clay wall, well defined	....
"vi. Milling ore (drift), taken out in parts	9½
"vii. Hard quartz	8
"viii. Hard quartz ore with veins of manganese spar	12
"ix. Hard country granite with veinlets of quartz and of manganese spar	....
	77½

* William P. Blake, Amer. Inst. Mng. Eng., Vol. XVI., 1887-88, pp. 70-72.

At the 700 foot level the section across the vein shows a width of forty feet.

The Gagnon vein.—As has already been stated, the two classes of veins in the Butte City district are characterized, the one by a preponderance of copper, the other by a preponderance of silver and manganese. The Gagnon vein, however, according to Mr. Richard Pearce,* is an exception and differs in several respects from any of the other copper or silver veins. It is characterized by a rich silver- and copper-bearing zinc blende, of a black color, and generally massive, though a few small crystals have been found. The mineral is supposed by Pearce to be wurtzite. In the same vein are also found small quantities of tungstate of manganese, or huebnerite, which represents the only manganese mineral found at this mine. As suggested by Pearce, the absence of other manganese minerals in the Gagnon vein is remarkable in consideration of their abundance in the surrounding veins.

THE MANGANESE DEPOSITS OF COLORADO.—*Gunnison county.*

Cebolla Valley.—Cebolla Valley is on the western slope of the Rocky Mountains, in the extreme southern part of Gunnison county. Manganese and iron ores have been found here two miles above Powderhorn Post-office, twenty-four miles southwest of Gunnison City, and eight miles east of the Lake City branch of the Denver and Rio Grande Railroad. The property is controlled by Mr. Lewis of Gunnison City.

The manganese occurs in limestone in the form of pockets or lenticular layers, from one to four feet in thickness. It is of a massive or faintly crystalline nature, of a steel-blue or black color, and has a hardness of about 5. In some places it is associated with hematite, and in others it occurs alone. It contains cavities lined or filled with white crystalline calcite, and in exposed positions often has a porous, honeycombed structure, due to the leaching out of the calcite and the included masses of limestone. The iron ore has a bright

* Amer. Inst. Mng. Eng., Vol. XVI., 1887-8, pp. 62-64.

black color, a submetallic lustre, a deep red streak, and like the manganese ore, often contains nests of white crystalline calcite.

The limestone enclosing these ores is a coarsely crystalline and more or less granular rock of a brown or dun color, and contains masses of white crystalline calcite. The rock decomposes by first passing into a porous, earthy mass, and then into a clay. Occasionally it contains strata of micaceous schist which are often considerably decomposed on the surface. The rocks strike in a general north and south direction, and dip at steep angles, from 60° to 80°. They form a high hill on the north side of Cebolla Valley.*

The manganese occurs in the limestone in a variety of ways, but it always shows a tendency to conform to the bedding of the rock, and in some cases it is found in well defined lenticular strata. It often occurs in pockets or nests, in very irregular quantities, sometimes being entirely absent, at other times composing several per cent of the mass of the rock, and from this increasing until the pockets run together, and form a solid bed.

Figure 37. *Section in the side of a tunnel on the Lewis lands, Cebolla Valley, Colorado, showing the mode of occurrence of the manganese ore.*

The black parts are manganese ore.

The enclosing rock is limestone.

Horizontal and vertical scale: 1 inch=8 feet.

The property has been partly prospected by a number of small tunnels and shafts, and the accompanying figure, taken from the side of one of the tunnels, shows a characteristic mode of occurrence of the ore. The small bodies of ore represent pockets in lines of bedding in the rock. The large body also represents a lenticular bedded deposit and, though more con-

* It is to be regretted that further details concerning the nature of the rocks and the structural features of this area cannot be given, but the property, when examined by the writer, was covered by snow which obscured much that might otherwise have been observed.

tinuous than the small ones, it also doubtless thins out at a greater or less depth. Below it, however, other pockets would probably be found, alternately thinning and thickening again just as those represented in the figure. In some places both manganese and iron ores are found in the same opening, and in others each occurs alone. No ore has yet been shipped, as the distance from railway transportation has thus far been an impediment to the development of the property.

An analysis of the manganese ore is given below, but it represents the ore in only one pit, and is not an average sample of the whole property.

Analysis of manganese ore from Cebolla Valley, Colorado.

Manganese	41.43
Iron	3.08
Silica	19.68
Phosphorus	0.36
Cobalt	trace
Manganese peroxide	55.90

Elkhorn Mountain.—Manganese ores have been found at Elkhorn Mountain * in the southwest part of Gunnison county, six miles north of the line of Hinsdale county. They occur in the neighborhood of hematite iron ores.

Taylor River.—Large quantities of manganiferous iron ore are also reported by Professor Regis Chauvenet † as existing on Taylor River in Gunnison county, twenty-seven miles north of Gunnison City, and thirteen miles from the Crested Butte branch of the Denver and Rio Grande Railroad. In speaking of them, he says: "A shaft, thirty-four feet in depth, is all in ore, and drifts in different directions, of ten and twelve feet, are still in the same mass. The same material is again struck fifteen hundred feet away. This, again, is probably a great 'bedded deposit.'" The deposit is a manganiferous iron ore in which the iron largely predominates, as is shown by the following analysis by Professor Chauvenet:

* Regis Chauvenet, Annual Report, State School of Mines, Golden, Colorado, 1887, pp. 18-19.

† Ibid., 1887, pp. 20-21.

*Analysis of manganiferous iron ore from Taylor River, Colorado.**

Manganese protoxide	13.92
Ferric oxide.	39.01
Lime	19.55
Magnesia	6.03
Carbonic acid	21.05
Silica	0.82
	100.38
Manganese	10.78
Iron	27.31

Professor Chauvenet says of this analysis: "The carbonic acid of this ore would be expelled by roasting, or by treating it in a kiln, like a common limestone. If we assume, as we may, that there will be no material variation in the remaining constituents, we would obtain a product of the following composition:"

Manganese protoxide	17.62
Ferric oxide	49.38
Lime	24.74
Magnesia	7.63
Silica	1.04
	100.41
Manganese	13.65
Iron	34.57

Elk Mountain and Tin Cup.—Manganese ores are reported on Elk Mountain in the northern part of Gunnison county; and also near the town of Tin Cup in the eastern part of the same county.

Steuben Valley.—Steuben Valley is in Gunnison county, six miles southwest of Gunnison City, and is a steep canyon running through a series of lavas and lava breccias.

Most of the ore is found in a breccia composed of angular and rounded lava fragments, from a fraction of an inch to several feet in diameter, buried in a sandy material of the same nature. The breccia forms a more or less coherent mass, in some places.

* Regis Chauvenet, Annual Report, State School of Mines, Golden, Colorado, 1887, p. 20.

hard and compact, in others soft and loose. It weathers into narrow upright pillars, often capped by masses of rock which have protected them from erosion.

The ore occurs as a black, highly siliceous oxide in cavities in the breccia, and frequently forms the matrix in which the lava fragments are imbedded. Its distribution is irregular, and it is seen only on the east side of the canyon, where it sometimes impregnates the bed for vertical and lateral distances of fifty and sixty feet, and probably in places for considerably greater distances. Sometimes the fragments of lava have decomposed into a fine powder which has been stained black with manganese.

Besides the ore in the breccia, however, manganese sometimes occurs in the massive lava: in the bottom of the canyon a low, narrow ridge runs north and south, and is composed largely of a black material resembling obsidian and containing scattered white or transparent crystals of feldspar. On the top of the ridge is an exposure of a yellow, brittle, hard, translucent rock with a conchoidal fracture, and containing small nests and seams of a milky white, siliceous material, probably opal or chalcedony. The rock is cut by veins of blue and red quartz. Manganese occurs in this rock as nests and veins from half an inch to six inches in thickness. The ore is black, massive, very hard and compact, and has a glossy, conchoidal fracture. The rock carrying the ore seems to occur as an oblong pocket about four feet wide. The length of the deposit carrying this ore is not seen, as the ground is largely covered by detritus, but it is probably limited.

A stain of manganese, or thin veins the thickness of a sheet of paper, are frequently seen elsewhere in the solid lavas, especially in the beds which cap the sides of the canyon and overlie the breccia, but it is in only very small quantities.

The following analysis shows the composition of the ore from this locality. The sample analyzed is said to have contained a considerable quantity of siliceous gangue, and therefore shows more silica than the ore normally contains:

*Analysis of manganese ore from Steuben Valley, Colorado.**

Manganese	36.60
Iron	5.64
Silica	35.32
Phosphorus	0.116
Manganese peroxide	52.30

Sapinero.—Manganese occurs four miles south of Sapinero, which is in Gunnison county, Colorado, on the Denver and Rio Grande Railroad, about thirty miles west of Gunnison City.

The ore is a black, highly siliceous oxide, sometimes showing a finely granular structure. It occurs in kidney-shaped or mammillary forms, in pockets from one inch to four feet in diameter; or as a network of thin veins, from an eighth of an inch to one inch in thickness, in a breccia somewhat similar to that described at Steuben Valley. The rock is composed of lava fragments, from one to twenty-four inches or more in diameter, buried in a sandy matrix composed of grains of the same material. This bed is overlain by a massive lava sheet, occasionally stained by manganese, but containing no quantity of that ore. The breccia directly overlies a large bed of sedimentary sandstone, considerably cross-bedded, varying from soft and friable to hard and flinty, and in color ranging from white to yellow or rusty brown. On the geologic map of the Hayden Survey† this rock is represented as Cretaceous. It is almost horizontal and rests immediately upon crystalline rocks.

The following analysis of the ore from this locality shows its composition:

Analysis of manganese ore from Sapinero, Colorado.

Manganese	27.94
Iron	2.63
Silica	31.19
Phosphorus	0.49
Cobalt	trace
Manganese peroxide	39.67

It will be observed that the ore is low in manganese and high in the injurious ingredients, silica and phosphorus.

* The analysis was made by the St. Louis Sampling and Testing Company, Professor William B. Potter, Manager, and was kindly furnished the Survey by Mr. William H. Wayland, Gunnison City, Colorado.

† F. V. Hayden, Geological and Geographical Survey of Colorado and Adjacent Territories, 1876.

THE MANGANESE DEPOSITS OF COLORADO.—*Leadville.*

Manganese ore, in association with iron ore, occurs as a gangue material in many of the silver-bearing deposits of Leadville, and is frequently shipped to smelting works at Pueblo and elsewhere to be used as a flux in the treatment of silver-lead ores. Iron usually forms the larger part of the mass, and therefore the ore is valued mostly for its contents of that metal, but manganese plays a similar part in smelting and the amount of it in the ore is paid for at the same rate as the iron. Sometimes, however, manganese occurs in very considerable quantities in the gangue and such ores are used in the manufacture of spiegeleisen and ferro-manganese. Considerable quantities are consumed by the Colorado Coal and Iron Company of Pueblo, and by the Illinois Steel Company of Chicago.

The manganese occurs either as a crystalline pyrolusite, or more often, as a manganiferous iron ore, and frequently as an earthy material partaking of the nature of wad, and known by the miners as "black iron ore." The iron is usually in the form of a brown hematite, and both it and the manganese are in variable quantities, sometimes occurring as a mere stain, at other times forming the larger part of the gangue of the other metals.

According to Dr. S. F. Emmons,* the most important metalliferous deposits at Leadville occur in the "Blue Limestone," of Lower Carboniferous age, at or near its contact with the overlying "White Porphyry," or "Leadville Porphyry." The contact with the porphyry is sharp and well defined, but with the limestone the ore blends into the rock, and sometimes extends deep into the bed.

Sometimes, also, the ore occurs at or near the contact of the "Gray" and other porphyries with the "Blue Limestone," and more rarely in still different associations.

Dr. Emmons in speaking of the occurrence of iron and manganese in the Leadville region, says: † "Iron and manganese might be more properly considered gangue materials.

* Geology and Mining Industry of Leadville, Monograph U. S. Geol. Survey, No. XII. 1886, p. 375.

† Ibid., p. 547.

They are mainly in the form of hydrated sesquioxide and protoxide, respectively. A little protoxide of the former and peroxide of the latter ore was found. The former may be combined as basic sulphate, which, as will be seen later, sometimes forms considerable bodies. The latter is probably anhydrous, as pyrolusite is frequently distinguishable in actual crystals and sometimes forms considerable ore masses. Although no actual pyrite was observed in the Leadville deposits, there is little doubt that iron existed in this form in the original deposits. With regard to the original form of manganese there is more uncertainty, as the sulphides of this metal are relatively rare. It sometimes occurs as carbonate, in association with sulphides of other metals, losing its carbonic acid when they are oxidized. It is so common an associate of iron in oxidized ores and so seldom noticed in unaltered sulphides that it might be thought to have been in part brought in as oxide during secondary alteration. It is possible that some of the iron in the ores may be combined with silica as silicate, and with arsenic as arseniate."

Dr. Emmons thinks that the metalliferous deposits in this region were laid down from aqueous solution, mostly in the form of sulphides, and that they were later oxidized near the surface; that the mineral matter came from above and was mainly derived from the neighboring eruptive rocks; and that the process of deposition was a metasomatic interchange produced by the substitution of the sulphides for carbonate of lime in the limestone.

The following analyses have been kindly furnished the Survey by Mr. I. Grove, Superintendent of the Colorado Coal and Iron Company of Pueblo. They represent the composition of twenty-three samples of manganese ore and manganiferous iron ore from Leadville and the surrounding region. The analyses marked with an asterisk are of ore used by the company in the manufacture of spiegeleisen or ferro-manganese.* The others are analyses made by the company of samples sent them for examination.

* Analyses of spiegeleisen and ferro-manganese made from these ores by the Colorado Coal and Iron Company are given on page 31 of this report.

Analyses of manganese ores and manganiferous iron ores from Leadville and vicinity, Colorado.

No.	Name of owner or of claim.	Locality.	Manganese.	Iron.	Silica.	Phosphorus.	Sulphur.
1	Fannie Barrett	Leadville	51.20	6.20	2.90	0.007	.....
2	Fuller	"	49.20	6.00	15.00	0.129	0.041
3	.....	"	40.56	1.33	4.70	trace	0.137
4	Pennsylvania mine	"	38.60	2.05	4.00	.....	.....
5	Evening Star	"	37.14	12.20	7.60	0.022	0.075
6*	J. B. Henslee	"	36.40	19.50	7.00	0.025	0.027
7*	John Harvey	"	34.64	18.20	8.00	0.033	.....
8*	Crescent Catalpa	"	34.00	17.80	6.30	0.045	.....
9	Fannie Barrett	"	33.00	6.20	6.10	0.008	.....
10*	George W. Hull	"	29.12	25 10	3.80	0.084	.....
11*	Ballou	"	24.69	32.14	4.40	0.022	0.178
12*	Catalpa	"	20.20	34.12	6.50	0.008	0.082
13*	"	"	20.14	36.82	6.83	0.007	0.021
14*	Parks & Hull	"	19.30	35.00	3 83	0.045	.....
15*	Henslee	"	18.66	26.42	8.49	0.040	.....
16*	George W. Hull	"	18.11	30.86	4.04	0.039	.....
17*	George W. Hull	"	16.20	43.30	3.10	0.012	.....
18	Maid & Hen	"	14.71	41.48	5.00	0.039	0.055
19*	Ballou	"	9.30	48.51	4.20	0.017	0.055
20	B. F. Allen	Allen	51.90	1.00	.....	.....	.....
21	Not known	Not known	47.21	1.95	8.21	trace	.....
22	J. C. Ward	Kirby Creek	44.70	4.20	6.25	0.104	.....
23	W. Marsh	Buena Vista	25.00	0.90	47.60	0.048	.....

Other localities in Colorado.—Besides the localities already described, manganese is found in small quantities in many of the metalliferous deposits elsewhere in Colorado. Among these localities are Lake City in Hinsdale county, Telluride and Red Mountain in Ouray county, and other places. It is generally, however, in very limited quantities in these places and of no commercial importance as a source of manganese.

*The analyses marked with an asterisk (*) are of ores used by the Colorado Coal and Iron Company in the manufacture of spiegeleisen or ferro-manganese. The others are of ores sent to the company for examination.

THE MANGANIFEROUS SILVER DEPOSITS OF NEW MEXICO.

Manganese, in the forms of oxide and carbonate, occurs in many of the silver-bearing deposits of New Mexico. Among the principal localities are those mentioned below.

Lake Valley mine.—The Lake Valley mine is in Sierra county, fifty miles northwest of Las Cruces. Manganese has been found here in the form of fibrous crystals of pyrolusite in association with silver ores.

Kingston.—Considerable quantities of manganese are found with the silver ores in the neighborhood of Kingston, Sierra county, especially at the Black Colt, Franklin, Comstock, and other mines on the middle fork of Percha Creek. The veins are said to occur in blue limestone and black dolomite. Manganese is characteristic of many of the deposits, and is considered a good indication for silver in that region. Some car-load shipments of silver ore are said to have contained as much as 60 per cent of manganese peroxide, equal to about 38 per cent of metallic manganese, but this quantity is exceptionally large.

At the Lady Franklin mine, in this district, the manganese is said to have been found in the form of manganocalcite, or carbonate of manganese and lime. At the Caledonia mine it sometimes occurs in the form of the rare mineral alabandite, a sulphide of manganese.

Silver City.—A manganiferous iron ore, said to contain an average of about 13 per cent of metallic manganese, is mined at Legal Tender Hill, Silver City, New Mexico, and is used at the El Paso smelting works as a flux for silver ores.

THE MANGANIFEROUS SILVER DEPOSITS OF ARIZONA.—*Tombstone.*

General features.—The town of Tombstone is in Cochise county, in the southeast part of Arizona, forty miles north of the Mexican line, and eight from Fairbank, a station on the New Mexico and Arizona Railroad.

Manganese, in the form of oxides, is a common constituent of many of the silver-bearing veins of this region. It does not form a sufficiently large proportion of the ores to be used as a

source of manganese, and even if it did it would not pay to use them for that purpose, as they are more valuable for their contents of silver. (See pages 448). The manganese, however, is of assistance as a flux in smelting, and consequently ores containing it have an additional value besides the silver they contain. According to Mr. Charles W. Goodale,* not less than 750,000 ounces of silver were obtained from such ores up to July, 1887.

The manganese occurs in the form of pyrolusite, earthy, black wad, and possibly as psilomelane and some of the other manganese oxides. These minerals are indiscriminately associated with either a calcareous or siliceous gangue, though the siliceous ores are generally the richer in silver. The carbonate and silicate of manganese, rhodochrosite and rhodonite, have not yet been found, at least in any quantities, in the Tombstone region. It is said, however, that none of the mines have gone as deep as the water level of the country, and it is not impossible that, as at Butte City, Montana, these minerals may yet be found at or below that depth. In large shipments the manganiferous silver ores are said to average about 5 per cent in manganese, though in individual localities they often contain several times this amount. The deposits occur as veins and "chimneys".

The prevailing rocks of the region are a series of limestones and quartzites with shaly or slaty strata, associated with porphyritic and feldspathic dikes, and granitic rocks.

The stratified rocks are exposed in a series of undulating folds frequently broken by faults. They are supposed by Prof. W. P. Blake† to be probably of Lower Carboniferous age. In speaking of them he says; "The fossils which have been found in the middle and upper beds, consisting chiefly of *Productus* and cyathophylloid corals, show them to be *Paleozoic*, and probably Lower Carboniferous. The lower strata are probably older. A small shell, like *lingula*, occurs in the shales of the Contention mine." The limestone is the predominating rock, and is compact, massive, gray or faintly pink. It sometimes shows

* Trans. Amer. Inst. Mng. Eng., Vol. XVII., 1888-89, p. 767.
† Ibid., Vol. X., 1881-2, pp. 335-6.

a slight tendency towards a semi-crystalline structure and contains numerous cavities lined with calcite. It is often very pure, containing over 90 per cent of carbonate of lime, and from this it becomes more and more siliceous until it eventually blends into a hard, translucent quartzite.

The Big Comet mine.—The Big Comet mine is the property of the Tombstone Mill and Mining Company. It is on a vein at the contact of the limestone with the intrusive porphyry. The vein dips at from 60° to 80° to the west, strikes in a general north and south direction, and varies from a few inches to over four feet in width. The limestone is much disturbed and dips at angles of from 10° or 15° to almost perpendicular. The vein matter is generally a soft, black mass devoid of structure. It has been followed down continuously for a depth of 300 feet and is still in the bottom of the shaft.

The following analyses of the ore from this mine have been kindly furnished the Survey by Mr. Geo. W. Cheyney, Manager of the Tombstone Mill and Mining Company.

Analyses of manganiferous silver ore from the Big Comet mine, Tombstone, Arizona.

	1.	2.
Manganese	15.0	14.8
Iron	1.8	2.0
Lead	1.0	0.4
Lime	32.4	34.8
Silica	5.2	8.2

Silver (at mine) $13.45 to $15.75 per ton.

Other analyses have shown as much as 20 per cent of manganese, with silver contents ranging from $13 per ton upwards.

The Knoxville mine.—The Knoxville mine represents the so-called "chimney" deposits. These are irregular bodies of ore of a roughly cylindrical form, dipping at high angles. They are usually limited in depth, though some of them have been followed down for a distance of four hundred feet without reaching the bottom. Mr. Chas. W. Goodale,* in speaking of the Knoxville mine, says: "There were no indications of ore

* Trans. Amer. Inst. Mng. Eng., Vol. XVII., 1888-89, p. 768.

until the drifts were within a few feet of the ore-bodies, where the walls of the crack were stained with black oxides of manganese and some carbonate. Small detached pockets of pure manganese oxide also indicated proximity to the chimneys, but these small bodies carried very little silver. The filling of the chimneys included, in a great variety of forms, pyrolusite, wad, and psilomelane. It is not improbable that a searching examination would have discovered the rarer oxides, braunite, manganite, and hausmannite. The gangue was quartz and calcite. Galenite, cerussite, pyromorphite, cuprite, melaconite, and malachite were occasionally observed, and the assay shows a little gold—about 1-100 of an ounce, or twenty cents to the ton.

"Caverns were found in the widest parts of the ore-bodies which were lined with snow white and crystalline calcite. The purest manganese ore formed the lining of the chimneys, the percentage of gangue being greater in the middle."

The Big Comet and Knoxville mines are only two of the several silver mines in the Tombstone district, in which considerable quantities of manganiferous silver ores are found, but they serve to show the general modes of occurrence of the deposits. Among the others are the Lucky Cuss, Wedge, and Luck Sure mines.

CHAPTER XVIII.

THE MANGANESE DEPOSITS OF NEVADA.

LOCATION AND GENERAL FEATURES OF THE DEPOSITS.

Manganese ores have been found in several places in northern and central Nevada, but as yet the quantity has proved to be limited. The only locality in which they have been worked as a source of manganese is at Golconda, where a few tons have been mined. The ore exists here as a lenticular bed in Pleistocene deposits, while elsewhere in the state it is found in limited and very uncertain quantities in association with silver ores or silver-lead ores.

The manganese exists in a variety of mineralogical forms: at Golconda it occurs as a massive oxide; at Austin as rhodochrosite, or diallogite, (carbonate of manganese); in the Mammoth district, Nye county, as huebnerite (tungstate of manganese); at Eureka as wad and in other forms. The nature and mode of occurrence of the ores vary greatly in different places, and the reader is, therefore, referred for details to the descriptions of individual localities given in the present chapter.

DESCRIPTIONS OF LOCALITIES.

Golconda; the ore deposit.—The settlement of Golconda is in northern Nevada, in the valley of the Humboldt River, and on the line of the Central Pacific Railroad. Manganese ore has been found three miles northeast of the town, on a part of the Havallah range locally known as the Edna Mountains, a short distance south of where the Humboldt River has cut its channel through the range.

Two small pits have been made on the manganese deposit, and thirteen and a quarter tons of ore are said to have been

mined in 1886 and shipped to San Francisco. The ore is said to have contained $3.00 worth of silver to the ton.

The ore is a massive, black, glossy oxide of manganese with a hardness varying from 3 to 4. It is generally of a more or less porous structure, often containing cavities lined with mammillary or stalactitic forms, and frequently shows apparent signs of bedding. At times it is earthy, soft, and pulverulent, and contains angular fragments of sandstone, shale, and limestone, from a quarter of an inch to six inches in diameter. Sometimes it is stained brown by iron.

The following analysis by R. N. Brackett shows the composition of a specimen of this ore dried at 110°–115° Centigrade:

Analysis of manganese ore from Golconda, Nevada.

Manganese protoxide (MnO)	65.66
Oxygen (O)	10.31
Ferric oxide (Fe_2O_3)	3.32
Alumina (Al_2O_3)	0.34
Cobalt oxide (CoO) *	not determined
Lime (CaO)	3.44
Baryta (BaO)	5.65
Magnesia (MgO)	1.26
Potash (K_2O)	0.35
Soda (Na_2O)	none
Water and organic matter	4.16
Phosphoric acid (P_2O_5)	none
Tungstic acid (WO_3)	2.78
Silica (SiO_2)	1.70
Total	98.97

Manganese	50.85
Iron	2.32
Tungsten	2.29
Phosphorus	none
Moisture	4.97

It will be seen that the ore is an impure oxide of manganese, being possibly a mixture of the peroxide and sesquioxide, though the impurities obscure its true nature. The most remarkable feature of this ore is the considerable amount of tungstic acid,

* There is more than a trace of cobalt present but the amount was not determined.

which forms 2.78 per cent of the mass, corresponding to 2.20 per cent of tungsten.

Though from a mineralogical standpoint the ore is impure, yet for commercial purposes the analysis shows a high grade material. It will be seen that it is high in metallic manganese, and low in impurities of an injurious nature, containing only 1.70 per cent of silica and no phosphorus. The presence of 2.20 per cent of tungsten would give additional value to the ore in the manufacture of certain kinds of hard steel. The sample analyzed represented the best quality of ore on the property, and car-load shipments would probably contain somewhat larger quantities of impurities and correspondingly less manganese.

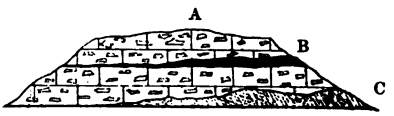

Figure 38. *Section through the Golconda manganese deposit.*
A. Calcareous tufa.
B. Manganese ore.
C. Shale.
Horizontal scale: 1 inch=125 feet. Vertical scale: 1 inch=80 feet.

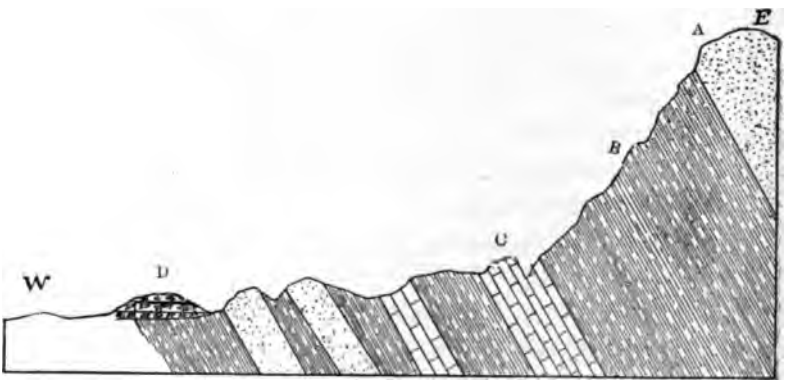

Figure 39. *Section showing the relation of the Golconda manganese deposit to the rocks of the Edna Mountains.*
A. Quartzite.
B. Shale.
C. Limestone.
D. Manganese-bearing deposit.
Horizontal scale: 1 inch=500 feet. Vertical scale: 1 inch=300 feet. (Both of these scales are only approximations.)

The ore occurs as a lenticular deposit interbedded in a soft,

white limestone, or calcareous tufa, containing fragments of sandstone, shale, and massive limestone, similar to those found in the ore and often in sufficient quantities to form a breccia. This material comprises a small knoll, about thirty feet in thickness, on the lower slopes of the mountain, and lies horizontally on the upturned edges of the underlying shales. The association of the manganese and tufa is shown in figure 38, while the relation of the deposit as a whole to the Edna Mountains is shown in figure 39. The first figure represents the small mound (D) on the left end of the second.

The outcrop of the ore bed appears as a horizontal black band along the side of the knoll facing the mountains, and is very variable in thickness, in some places being represented only as a black line in the limestone, and in others widening to a maximum, where exposed, of three and a half feet. On the western slope of the knoll the ore bed is not seen at all, the only trace of it being an occasional black stain or dendrites in the limestone along the line where it should outcrop if it extended through to this side. The bed also thins out to the north and south, the whole length of the outcrop being only about 400 feet. East of the exposure of the ore bed, the knoll is cut off sharply, as shown in figure 39, by a rocky area which separates it from the mountains. It will thus be seen that the amount of ore here is limited and it is probable that the area underlain by it does not cover more than a few acres.

Beneath the ore bed, as seen in one of the pits, the calcareous deposit is soft and partakes of the nature of a marl, while above, it is often much harder, and has in many places become coarsely crystalline, forming a hard limestone. The crystallization seems to have taken place in spots in the bed, and frequently bodies of crystalline limestone are surrounded by, and blend into a massive and softer material of the same composition.

The fragments of sandstone, shale, and gray limestone, found in this deposit, are of the same nature as the beds of those rocks which comprise the mountain to the east. The pieces of limestone are so markedly different from the calcareous bed enclosing them that they cannot be confounded with it. The rock

fragments are of unequal distribution in the deposit both laterally and vertically, sometimes composing almost half of it and sometimes being almost entirely absent. They vary from a fraction of an inch to eight or ten inches in diameter and are indiscriminately mixed.

The age of the rocks composing the part of the Havallah Range immediately east of the manganese deposit is represented as Star Peak Triassic on the map accompanying the Survey of the Fortieth Parallel.* As shown in the section, they are composed of sandstones, shales, and limestones, dipping at steep angles. Their uptured edges are well exposed from the summit of the mountain to its base, where they are covered by the mound containing the manganese deposit.

The crest of the mountain is composed of a quartzite which is of dark gray color, spotted with brown specks, of a granular structure, very hard, and cut by numerous quartz veins. The lower beds of quartzite on the slopes of the mountain resemble this one in all respects except that they show less trace of their original sandy structure and are more vitreous.

The larger part of the slope of the mountain is composed of a more or less slaty shale. It is of a gray or purple color, contains large quantities of thin flakes of mica, has a wavy undulating structure, and in many places grades into a micaceous or talcose schist. The lower beds of shale are much thinner than this one, and in some places resemble it in general appearance, while in others they are more calcareous and blend into limestone. The shale which is seen at the base of the knoll containing the manganese (figure 39) is of a light yellow color, and is made up of thin, friable laminae.

The limestone beds shown in figure 39 are all of much the same character; they are of light or dark gray color, sometimes with a reddish tinge, generally massive, though occasionally showing a tendency to a semi-crystalline structure, and are frequently cut by veins of white, crystalline calcite.

* U. S. Geol. Exploration of the Fortieth Parallel. Clarence King, Geologist in charge; Vol. I., Systematic Geology, map III., Pre-Mesozoic and Mesozoic exposures. See also report of Arnold Hague, Vol. II., Descriptive Geology, p. 680.

Golconda; the derivation of the ore deposit.—The Golconda manganese deposit is in the arid region lying between the Rocky Mountains and the Sierra Nevada, and known as the "Great Basin." Parts of this region were, in late geologic times, covered by several large inland bodies of water, of which Lakes Bonneville and Lahontan, described respectively by G. K. Gilbert* and I. C. Russell,† were the largest. In subsequent times, these were mostly dried up, and the only remains of them now are a series of much smaller lakes occupying hollows in the bottoms of the old basins. Great Salt Lake is the modern representative of Lake Bonneville; and Tahoe, Winnemucca, Pyramid, and other lakes occupy the basin of Lake Lahontan.

The region about Golconda is on the eastern edge of the area defined by Mr. Russell as the ancient bed of the now extinct Lake Lahontan, and occupies a position at the head of a small bay which once protruded some fifteen miles up the valley of the Humboldt River, and marked the extreme eastern limit of the lake. Mr. Russell‡ in speaking of the Lahontan region says: "The basin of Lake Lahontan is one of the many independent drainage areas of which the Great Basin is composed, and its geology is a page in the history of the vast region lying between the Rocky Mountains and the Sierra Nevada." * * "The valleys which are now dry and treeless, and in many instances absolute deserts, destitute of any kind of vegetation over hundreds of square miles, were then occupied by lakes, the largest of which were comparable in extent and depth with those now drained by the Saint Lawrence. Some of these old lakes had outlets to the sea and were the sources of considerable rivers, others discharged into sister lakes; a considerable number, however, did not rise high enough to find an outlet, but were entirely inclosed, as is the case with the Dead Sea, the Caspian, and many of the lakes of the Far West at the present time."

Lake Lahontan did not overflow, and therefore the mineral

* Lake Bonneville, Monograph U. S. Geological Survey, No. I., 1890.

† Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885.

‡ Ibid., p. 6.

matter brought to it in solution by tributary waters constantly increased in quantity, and the gradual evaporation of the lake steadily concentrated these mineral solutions, until they arrived at a state of supersaturation and were deposited as chemical precipitates. These were, according to Mr. Russell, largely of a calcareous nature and were laid down as fringes on the margin of the lake at successive stages of evaporation. They are found now at different levels on the old lake border and mark the ancient shore lines. Mr. Russell has divided them into three classes of "tufas" differing considerably in physical character, and deposited at different levels in the lake's history. He has named them, in the order of their chronological succession, "lithoid," "thinolitic," and "dendritic" "tufas." The "lithoid tufa" was deposited during the early stages of evaporation in the lake, and occupies a position on the sides of the mountains which once formed the ancient lake shores.

From the analogy of the samples of tufa collected at the Golconda manganese deposit with the description of "lithoid tufa" given by Mr. Russell, and from the position that the deposit occupies in the old lake basin, it is probable that the calcareous material found with the Golconda manganese represents the "lithoid tufa," and that the manganese itself is a local deposit not necessarily characteristic of the variety of tufa with which it is there associated. In other words, the deposit repreents a lenticular bed of manganese ore interstratified in a calcareous sediment chemically deposited from supersaturated lake waters. It will be seen on figure 39, page 471, that the manganese bed occupies a basin in this tufa, that the basin was originally cut off on its east side by the rocks that formed the old shore line, and that it was bounded on its west side by the outer edge of the tufa terrace. Between these limits it extended a short distance up and down the lake shore. This position as well as the nature of the ore both tend to show that the bed was originally laid down as a shallow water deposit, and subsequently covered over by the same tufa that underlies it.

It seems possible that the source of the manganese was a

local accumulation precipitated from spring waters. In support of this supposition it may be stated that at the town of Golconda there are, at the present time, a series of hot springs depositing a sinter highly charged with oxide of manganese. The source of this ingrédient in the spring waters may have been in the lavas which cover large areas in the region in question and give strong reactions for manganese. Another possible source of supply may have been in the stratified rocks already described as forming the mass of the mountain on the slope of which the deposit is situated, as both the quartzite and the limestone contain small quantities of manganese. The lava, however, contains a much larger percentage of this ingredient than the other rocks.

As regards the mode of precipitation of the manganese, it is not probable that the ore was deposited simply by the gradual desiccation of the lake waters, as was the case with the "lithoid tufa" enclosing it, since if this had been so a far more general distribution of manganese than is seen in the tufa of the Lahontan basin would be expected. It seems more probable that the ore was a local precipitation brought on by an excess of manganese in spring waters in the locality in question, and that the cause of its accumulation was the accidental formation of a suitable basin in the tufa. This basin may either have been closed or have had an outlet into the lake. When the spring waters reached the surface they were retained at least temporarily in the basin, long enough to allow the oxidation of the metalliferous solution and the precipitation of oxide or simple carbonate of manganese,* thus causing the local accumulation of ore; whereas if the spring water had flowed directly into the lake, its contents of manganese would have been scattered over a vast area. The rock fragments in the ore and tufa represent detritus which rolled down from the mountain side during the deposition of the beds.

Austin.—The mineral rhodochrosite, or diallogite, (carbonate of manganese) is found in association with quartz in many of the silver-bearing veins near Austin, Lander county, Nevada.

*If the carbonate was precipitated it was later converted into its present oxide form. (See final chapter of this report.)

It is of a pink color and highly crystalline. It is not in sufficient quantities to be used as a source of spiegeleisen or ferromanganese.

Mammoth district.—Tungstate of manganese is reported as existing in the Mammoth district, Nye county, Nevada, though but few details regarding its occurrence and extent are obtainable.

The mineral was first described by E. Riotte.* According to him it has a brownish-red or brownish-black color, a yellowish-brown streak, a lustre which is adamantine on the cleavage plane and otherwise greasy; contains tungstic acid (WO_3) 76.4 per cent, and manganese protoxide (MnO) 23.4, equal to tungsten 60.59 per cent, manganese 18.12 per cent. It is said to occur in slate, in veins with scheelite, fluorite, and apatite.

Eureka.—Wad and other manganese-bearing minerals are found in association with the silver-lead ores of Eureka, Nevada.†

* Reese River Reveille (Quoted in Amer. Jour. Sci., Vol. XLIII., 1867, pp. 123-124.)

† J. S. Curtis, Monograph United States Geological Survey. No. VII., 1884, p. 59.

CHAPTER XIX.

THE MANGANESE DEPOSITS OF CALIFORNIA.

LOCATION OF THE DEPOSITS.

Manganese ores occur in many places in California, mostly in the Coast Ranges and to a lesser extent in the Sierra Nevada. Up to the present time, however, with one or two exceptions, they have been found in only small quantities. In the Coast Ranges they have been worked to a limited extent; in the Sierra they have not been worked at all.

The Sierra Nevada and the Coast Ranges run in a general northwest and southeast direction through California. The former range occupies the eastern part of the State and separates the arid regions of Nevada from the fertile Valley of California. It is by far the higher of the two ranges, and reaches an elevation, in some places, of over 15,000 feet. The Coast Ranges skirt the Pacific border and rise from a few hundred to 5,000 or 6,000 feet and more above the sea. They are much less rugged and barren than the Sierra, and are frequently covered with a dense growth of timber. Both the Sierra and Coast Ranges blend into each other in the northern and southern parts of the state, and the intermediate area, representing the Valley of California, comprises the drainage basins of the Sacramento and San Joaquin Rivers. The former rises in the mountains of the northern part of the state and flows south; the latter rises in Tulare Lake, in the southern part of the state, and flows northwest. Both meet in Suisin Bay, and flow thence through and the Bay of San Francisco, reaching the ocean through the Golden Gate.

The manganese ores of both ranges occur at various points on the interior border of this intervening valley region.

HISTORY OF MANGANESE MINING IN CALIFORNIA.

The history of manganese mining in the United States in general has already been given in chapter III., but for the sake of convenience the facts relating to California are summarized below.

The only properties from which any quantity of manganese ore has been shipped, so far as known, are Corral Hollow in San Joaquin county; Red Rock island in the Bay of San Francisco; and near Saucelito in Marin county. Ore is also said to have been mined in Santa Clara county, but no details concerning the quantity produced are obtainable. Besides these localities, many others from which no ore has yet been shipped, are known, and some of them have been prospected. They are described later in this chapter.

The first manganese mining in California is said to have been done in 1867, by A. S. Ladd, at the Old Ladd mine in Corral Hollow; though about the same time Red Rock island was also worked. Most of the ore from both places was sent to England and used in chemical manufactures. Ladd continued work until 1874, during which time he shipped about 5,000 tons of ore. The exact amount of ore shipped from Red Rock is not known, but it is said that at least one schooner load was mined, and probably more. Operations are said to have been stopped at an early date by the government authorities, who wished to preserve the island for harbor purposes.

In 1874 the introduction of Spanish manganese into English and other foreign markets caused the cessation of shipments of the California ore, which could not compete with the more accessible and often better product from Spain. Since that time manganese mining in California has been carried on to only a limited extent. The Old Ladd mine was purchased from Mr. Ladd in 1874 by Mr. Justinian Caire, of San Francisco, who since then has mined limited quantities of ore.

In the year 1882 the locality near Saucelito was worked to a small extent to supply a fluxing material for a smelter at that town. Only very small quantities of ore were mined and at present none is being produced.

The only manganese mining now carried on in California is the limited work at the Old Ladd mine, and even this plays no important part in the industries of the state. In fact, the work that was once done has been almost entirely forgotten, the subject excites no general interest and information concerning the different localities and their history is difficult to obtain.

THE GEOLOGIC RELATIONS OF THE MANGANESE DEPOSITS.

The manganese ores on the east and west of the Valley of California vary both in character and in the geologic ages of the rocks with which they are associated. In the Coast Ranges, on the west, the ores are associated with a series of jaspers, or phthanites, which were early recognized by Professor J. D. Whitney* as of Cretaceous age, and later described by G. F. Becker† as belonging to the Neocomian division of that age (Knoxville group). In the Sierra Nevada, on the east of the valley, the ores are associated with the limestone belt described by Professor Whitney as probably of Carboniferous age. Small quantities of manganese have also been found in the auriferous slate of the Sierra. The lithologic associations and the modes of occurrence of the ores are very different in the two regions, and the areas are therefore treated separately.

THE MANGANESE DEPOSITS OF THE COAST RANGES.

Location.—Manganese has been found at various points in the Coast Ranges, from Santa Clara county on the south, to Colusa county on the north, a distance of about two hundred miles. Beyond these limits, both on the north and the south, it is probable that similar ores may also be found when looked for.

Mineralogical forms of the ores.—The manganese ores of the Coast Ranges occur as oxides in the massive form, no crystalline ore having been seen at any of the localities visited, though it is possible that a further search may reveal their presence. The ores are in pockets or lenticular beds and not in the shape of

* Geological Survey of California, Vol. I., Geology, 1865.

† Geology of the Quicksilver Deposits of the Pacific Coast, Monograph U. S. Geol. Survey, No. XIII., 1888, pp. 271-272.

the nodules characteristic of the Appalachian region. From a mineralogical standpoint they are generally impure, but for commercial purposes many of them, where found in sufficient quantities, can be made of considerable value. Two principal varieties of ore have been distinguished, one probably representing the mineral manganite, the other an oxide containing a large amount of siliceous impurity which obscures the true mineralogical nature of the ore.

Manganite.—Specimen from the Richards claim, Corral Hollow, San Joaquin county, California. This is a massive, black, opaque mineral; lustre submetallic; often contains hollow cavaties lined with a jet black, glossy film; streak dark brown; fracture subconchoidal; hardness 4; specific gravity 3.76. The specific gravity is low for that of manganite, which usually varies from 4.2 to 4.4,* but this difference may be partly due to the presence of the impurities shown in the analysis below. The mineral contains numerous cavities, and to avoid error from these, the specific gravity was determined in a powdered specimen.

In a closed tube the mineral gives off water; in hydrochloric acid it dissolves with the evolution of chlorine and leaves a slight residue; with fluxes it gives manganese reactions. The following analysis made by R. N. Brackett shows its composition dried at 110°-115° Centigrade:

Analysis of manganite from Corral Hollow, California.

	Per cent.	Ratio.
Manganese protoxide (MnO)	75.26	1.063
Oxygen (O)	6.94	.434
Ferric oxide (Fe_2O_3)	3.26	
Cobalt oxide (CoO)	trace	
Lime (CaO)	3.10	
Baryta (BaO)	none	
Magnesia (MgO)	0.56	
Potash (K_2O)	0.19	
Soda (Na_2O)	0.58	
Water (H_2O)	8.46	.470
Silica (SiO_2)	1.98	
	100.33	

* J. D. Dana, System of Mineralogy, fifth edition, 1883, p. 171.

The analysis shows the specimen to be an impure oxide of manganese containing water, and approaching manganite in composition. The impurities, however, render it impossible to determine the mineral with certainty. The theoretical composition of manganite is represented by the formula Mn_2O_3, H_2O, in which the ratio of MnO, O, and H_2O is 2 : 1 : 1. The ratio of the California specimen as given in the analysis differs somewhat from the theoretical ratio, but it is sufficiently close to strongly suggest the identity of the mineral with manganite. Occasionally there is associated with this mineral a massive, steel-blue ore with a submetallic lustre, a conchoidal fracture, and a hardness of 6. It occurs in thin layers alternating with thicker layers of the ore just described.

Impure oxide of manganese.—Specimen from Red Rock, Bay of San Francisco, California. This is a massive, steel-blue mineral; opaque; lustre submetallic; powder dark brown; fracture conchoidal, well developed; hardness 6 to 7. It is often laminated in structure, the laminae sometimes following undulating lines much like those of the siliceous shales, or phthanites, which enclose the ore. Frequently cavities are found in it, lined with bright, glossy, mammillary surfaces or botryoidal protrusions. Sometimes, especially on an exposed surface, it is soft and earthy.

The following partial analysis by W. A. Noyes shows the composition of the mineral dried at 110°-115° Centigrade:

Analysis of impure oxide of manganese from Red Rock, California.

Manganese protoxide (MnO)	44.21
Oxygen (O)	7.31
Ferric oxide (Fe_2O_3)	5.32
Alumina (Al_2O_3)	1.44
Phosphoric acid (P_2O_5)	0.61
Silica (SiO_2)	35.32
	94.21

The analysis, as will be seen, shows a very impure material. The physical features of the ore, however, are those of psilomelane and it is possible that it represents a highly siliceous specimen of that mineral.

This form of ore is the common one at Red Rock, and an apparently similar ore occurs near Saucelito, Marin county.

Commercial value of the ores.—It will be seen from the descriptions given above, that there are two varieties of manganese ore in the Coast Ranges, both black and massive, but one comparatively soft, the other hard and flinty. The softer variety, so far as can be judged from the one analysis, is rich in manganese and low in the injurious ingredients, silica and phosphorus. The analysis shows an excellent ore for the manufacture of spiegeleisen and ferro-manganese. The harder variety of ore is comparatively low in manganese, high in silica and medium in phosphorus. Further chemical tests, however, may prove some of it to be of better quality. The amount of peroxide available for commercial chemical purposes is small in both ores. The analyses given below show the composition of the two different ores. These analyses are the same as those just described, but they are stated in a different manner, so as to bring out their commercially important features.

Analyses of manganese ores from California.

CONSTITUENTS.	Corral Hollow *	Red Rock.
Manganese	58.28	34.23
Iron	2.28	3.72
Silica	1.98	35.32
Phosphorus	none	0.27
Lime	3.10	.....
Manganese peroxide.	37.71	89.75

Mode of occurrence of the ores.—The manganese ores of the Coast Ranges, so far as yet known, are confined to a series of metamorphosed shales, described by Prof. J. D. Whitney † under the name of jasper, and by G. F. Becker ‡ under the name of phthanite.

The geologic relations of these rocks have already been

* The analysis of the ore from Corral Hollow was made of a picked sample.

† Geological Survey of California, Vol. I., Geology, 1865.

‡ Geology of the Quicksilver Deposits of the Pacific Coast, Monograph U. S. Geol. Survey, No. XIII., 1888, p. 105-108.

mentioned on page 480. The ore usually occurs as a more or less distinctly bedded deposit, generally following the lines of stratification, but sometimes cutting across them and filling joint cracks or lines of faulting. These transverse leads, however, are much smaller than the bedded ones and are always tributary to them, rarely reaching any great distance from them before they thin out and disappear. They seem to have been formed from the bedded deposits by chemical action, whereby they were dissolved and re-deposited during or after the disturbance of the of the rocks. The bedded deposits vary from a mere black film between strata to beds several feet in thickness, and sometimes seem to partake of the shaly nature of the enclosing rock. Such deposits are not continuous over any great distance, but occur as lenticular layers, or oblong and somewhat abrupt pockets, following certain lines of stratification and either connected by thin seams of ore or separated by practically barren rock. These lenticular bodies vary greatly in a given distance, and in some places coalesce, forming a continuous bed of varying thickness for a distance of several hundred feet along the outcrop of the ore-bearing stratum. Such is the case at the Old Ladd mine, to be described later in this chapter.

The jasper, or phthanite, with which the ores are associated varies in color from gray, yellow, and green, to brown and brilliant red. The gray and red colors are the most common; and the latter, more by its brilliant shade than its more frequent occurrence, is markedly characteristic. Of so deep a hue is the red coloring, that the rock, especially where weathered and soft, has been used as a basis for paint. This striking color has given the name to Red Rock island, to be described later in this chapter.

These rocks are very hard and flinty, with a fracture varying from hackly to conchoidal. In the neighborhood of the manganese deposits, they are sometimes deeply stained with a black manganese coloring matter, either as a thin film penetrating cracks and joints or as a finely disseminated material which has impregnated the whole substance of the stratum. The rocks

are sometimes bedded in thin laminae, at other times in more massive strata from several inches to several feet in thickness; and between these stages these are all gradations, the thin and thick strata being indiscriminately associated. Such deposits, according to Whitney and to Becker, are the result of the metamorphism of shales, and in many places blend into the unaltered rock. The transition from one rock to the other takes place both laterally and vertically, and the extent of either one is very irregular.

Not only have the beds been thus altered, but, where the proper constitutents existed in them, numerous more or less complex minerals have crystallized out during the metamorphism. Irregular masses as well as extensive deposits of serpentine are also frequently associated with the jaspers, and, according to Whitney and Becker, have resulted from the alteration of more or less impure sandstones, in the same way that the jaspers or phthanites have resulted from the alteration of shales.

The rocks with which the manganese is associated have all been greatly disturbed, and frequently dip at high angles, sometimes vertically. They occupy a belt of country, running in a general northwest and southeast direction, and frequently strike in that direction also, but the disturbances in many places have greatly contorted and confused the strata. G. F. Becker,* in speaking of the time of the disturbance of these rocks, says: "The epoch of the uplift lies between the end of the period in which the Knoxville and Mariposa beds were deposited and the beginning of that in which the unmetamorphosed Wallala series was laid down, or, according to the paleontological determinations, between the Neocomian and a middle Cretaceous period resembling the Gosau. Unless the violent dislocation which took place between these periods was preceded by a gentle uplift of the country above water—and of this no evidence is known—the folding and crushing which form so prominent a feature of the Coast Ranges must have taken place at the close of the Neoco-

* Geology of the Quicksilver Deposits of the Pacific Coast, Monograph, U. S. Geol. Survey, No. XIII., 1888, p. 132.

mian." Mr. Becker is also of the opinion that the metamorphism cannot have preceded the uplift, but that it occurred immediately after it and was "to a great extent dependent on the crushing of the rock."

The Old Ladd or Corral Hollow mine.—This property is in San Joaquin county, in a canyon known as Corral Hollow, twelve miles south of the Southern Pacific Railroad at Tracy, and about fifty miles southeast of San Francisco. It was originally owned by A. S. Ladd, who did the first mining on it in 1867; hence the name, "Old Ladd mine." It represents the locality from which most of the California production of manganese has been derived, and its history is given on pages 479–480. It is now owned by Mr. Justinian Caire of San Francisco and is worked to a limited extent. Considerable mining has been done on the property: a tunnel about 500 feet long has been run into the hill and numerous small pits have been worked.

The manganese occurs in a lenticular bed interstratified in red, yellow, and gray jasper. The ore, when fresh, is a hard, black, massive variety, with a well developed conchoidal fracture, and sometimes showing a tendency towards a laminated structure. On an exposed surface it becomes soft and breaks up into a fine black powder. It resembles, externally at least, the mineral described on pages 481–482, which is from a different part of the same bed. The jasper is frequently stained in joint cracks and cavities by a thin black film of oxide of manganese, and is also pierced by many veins of quartz. It has been much folded and now forms a hill rising almost 300 feet above the surrounding drainage. The strata all dip at steep angles of from 40° to 90° and strike in a general direction of north-of-west.

The outcrop of the manganese bed appears on the west side of the hill and has been traced continuously across the summit. In runs in the direction of the strike of the rock and has been followed by a tunnel for about five hundred feet. The ore bed was found to widen and contract at intervals, expanding in some places to as much as seven feet, and in others thinning out altogether. In fact, it is made up of a series of irregular and somewhat abrupt lenticular bodies, either near together and

connected by thin seams, or more or less completely isolated and separated by many feet of barren rock. Frequently there are small subordinate bodies of ore in the jasper on either side of the main deposit, but they all seem eventually to run into the latter. In places the contortions of the rocks have thrown the ore bed into small folds, and it is found lying horizontally at the crest of such disturbances; but this is of only local occurrence the deposit usually dips steeply with the enclosing rock.

What appears to be the extension of this same manganese bed was traced almost continuously for a quarter of a mile in a west-by-north direction, and over a mile in an east-by-south direction. It thins and thickens at intervals, and at times runs out altogether, beginning again a short distance farther on, just as at the Old Ladd mine. In no place was more than four hundred yards passed without seeing signs of it, and if the outcrop were stripped, it is probable that the exposures would be still closer.

A quarter of a mile north-by-west from the main mine is a small pit showing the ore-bearing deposit with a width of from five to six feet of soft black ore, bounded on each side by the yellow and gray jasper.

The Richards claim.—The Richards claim is a little over a mile in a general southeast direction from the Old Ladd mine, and appears to be on the continuation of the same ore bed. The outcrop of the deposit is traceable at intervals for about a thousand feet, and is four feet in the widest part, thinning to one foot at its southeast extremity. It strikes in a north-of-west direction and dips almost vertically. The same red and gray jasper that have already been mentioned form the country rock. An analysis of the ore from this property is given on pages 481 and 483.

Red Rock.—Red Rock is a small island situated in the northern part of the Bay of San Francisco, about three miles south of San Pablo Point, and fifteen miles north of the city of San Francisco. It is of a rudely circular shape and rises steeply from the water's edge to a height of about a hundred feet. It has an area of about three or four acres.

Manganese was mined on this island about the year 1867 and was shipped to England. The exact amount of ore taken out is unknown, but it is stated that at least one schooner-load, and probably more was mined.* A small tunnel and an open cut were made, but the amount of work done was limited.

The manganese occurs in association with red jasper and is of a hard, compact, massive nature, very brittle, with a sub-metallic lustre, a deep steel-blue color, a conchoidal fracture, and occasionally a laminated structure resembling that of some of the enclosing rock. The jasper has a deep blood-red color, though it is frequently stained along cavities, joints, fault lines, and especially planes of bedding by a black film of oxide of manganese, which gives the rock a beautifully banded appearance. The red varieties, where soft and decomposed, have been used as the basis for a paint. The jasper is much disturbed, but its general dip varies from south to west, though the contortions have caused considerable irregularity in the uniformity of the strata. It comprises the southwest part of the island and rises in an almost vertical cliff, conspicuous by its brilliant red color, and hence the name of the island. At this point the strata are almost vertical, while to the northeast they lie at lower angles, and in places are almost horizontal. Rising from under the jasper and forming the northeast part of the island is a softer, yellowish-green rock, comprising an area much lower than the other part of the island, and sloping off gently to the bay. This rock sometimes appears to be stained with manganese, but does not contain any considerable quantity, and the ore so far as seen is practically confined to the jasper.

The ore occurs both in the planes of bedding and in joint cracks and faults in the form of more or less continuous seams, varying from a mere film to a foot in thickness. The seams in the bedding planes are apparently the most constant, while the others probably represent the result of a secondary chemical action, by which the ore has been carried in solution from the bedded deposits into fracture caused by the disturbances in the rock. The quantity of ore on the island is very limited.

* For further details see page 479.

San Francisco.—A jasper similar to that already described, and containing small quantities of manganese, is seen in the city of San Francisco, especially on Bernal Heights, at the quarries at 22d and Castro streets, on 19th street between Castro and Noe, in Golden Gate Park, and elsewhere. Sometimes lumps of manganese ore are found in these places, and the jasper is more or less stained with it, but the quantity is insignificant and the localities are mentioned only to show the general distribution of small quantities of manganese in the metamorphosed shales of of the Coast Ranges.

Tomales and Preston's Point.—Similar jasper with a similar stain of manganese occurs one mile east of Tomales, in Marin county, and also on Preston's Point, two and a half miles southwest of Tomales, but in neither place has any appreciable quantity of ore been found.

Saucelito.—Saucelito is on the southern part of a chain of mountains separating the northern part of the Bay of San Francisco from the Pacific Ocean, and ending abruptly at the Golden Gate. Manganese ore has been found in small quantities in several places in these mountains just west of Saucelito. It was mined in about the year 1882, for use as a flux in a smelter at that town, but work was shortly afterwards abandoned. A few shallow pits were opened, but only small quantities of ore were mined.

The mountains rise several hundred feet above the waters of the bay, and are composed largely of shales in various stages of metamorphism, from an earthy, soft, unaltered material, to a hard, flinty jasper. They are of a deep red color, though often locally stained black with oxide of manganese. The openings have been made near the summit of one of the mountains, where the stain becomes much more marked, and the thin films of ore occasionally widen into nests or pockets from one to three feet or more in diameter. The ore is a massive, sometimes porous, bright, glossy, black material, hard, with a submetallic lustre on a fresh fracture and dull appearance on a weathered surface. It is frequently stained by iron. The jasper is much disturbed and is often cut by a network of thin veins of white quartz,

giving it a brecciated appearance and a variegated color. No considerable quantities of manganese ore are seen at this locality.

Little Stony.—The village of Little Stony, also known as Smithville, is in Colusa county, near the head waters of Little Stony Creek, and about twenty miles west of the Southern Pacific Railroad. Manganese has been found in several places from three to four miles northwest of the village, on the eastern foot-hills and the flanks of St. John Mountain, one of the peaks of the main chain of the Coast Ranges.

At one of these localities, on a claim owned by Messrs. Smith and Sisk, of Little Stony, a small opening has been made but no ore has yet been shipped. The manganese occurs in the same jasper, or metamorphosed shale, that has been mentioned before, except that in some places the rocks are less brilliantly colored and are often of a drab gray. They are frequently pierced by innumerable veins of white quartz. The ore is hard, black, and massive.

The jasper dips almost vertically, and strikes west-by-north. The ore-bearing part of the rock is from five to ten feet in its widest part and has been traced in the direction of the strike for about 200 feet. It appears to represent an interbedded stratum in the jasper, and is not composed entirely of ore, but contains it in quantities varying from less than a fourth to almost half the mass of the bed.* Traces of manganese appear elsewhere on the hill and frequently the

* Small nests, from a sixteenth to an eighth of an inch in diameter, of a red or crimson mineral, sometimes crystalline, occur sparingly in the ore. It seems to be cinnabar, but as the specimens collected were lost in transportation, no chemical tests were made. The same material frequently impregnates joints in the ore. The presence of cinnabar in the jasper, or phthanite, is a frequent occurrence, though it is also associated with various other rocks. G. F. Becker, (Monograph U. S. Geol. Surv., No. XIII., 1888, p. 391.) in speaking of the rocks in which this mineral occurs, says: "The country rock of the cinnabar deposits is of the most varied character, and I am unable to see that, excepting from a mechanical point of view, the rock has exerted any influence on deposition. The oldest rock in which cinnabar occurs is granite, in which the main part of the deposit at Steamboat Springs is found. The ore occurs in every variety of the early Cretaceous rocks, in unaltered sandstones, and also in phthanite, pseudodiabase, pseudodiorite, glaucophane schists, and serpentine. The most important deposits occur in the metamorphosed rocks, but this seems to be due only to their hardness, as will be explained a little later." Mr. Becker supposes the ore to have been brought from below and to owe its presence to a "precipitation in fissures from ascending hot solutions." (Loc. cit., p. 416.)

rock is impregnated with it in every available crevice, but except in the place just described it exists in only insignificant quantities.

A mile and a half northwest of this locality and on the slope of St. John Mountain, a similar ore occurs in a similar rock. The jasper has more of the characteristic red color than at the last place, and often blends into the unaltered shale, from which it was originally derived. The part of the rock containing the manganese is about twenty feet thick, with ore irregularly scattered through it and forming only a small fraction of the mass. The ore is traceable for a few hundred feet in the direction of the strike, when it becomes covered by debris from the mountain side. Between this locality and the last there is a similar but smaller deposit, and others are also reported at various places from five to ten miles south of Little Stony. In fact, the whole Coast Ranges from the peninsular of San Francisco northward to Colusa county, and probably beyond, is characterized at intervals by a stain of manganese, which occasionally increases in quantity until it blends into the local deposits already described.

THE MANGANESE DEPOSITS OF THE SIERRA NEVADA.

Location and general features.—The few manganese deposits that have so far been found in the Sierra Nevada in California, occur on the western slope of the mountains in Tuolumne, Caliveras, Placer, and other counties. They are very limited in extent, and have, so far, proved of no economic importance. No manganese ore has ever been shipped from any of them. They are found in connection with the auriferous slate and limestone of the Sierra, either in place in the rocks or as nodules in the auriferous gravel which covers their decayed surface.

The ores are found both in the form of oxide and of silicate of manganese (rhodonite). Their mode of occurrence is very different in different places, so that no further generalizations can be given here, but the details of individual localities are described below.

Sonora.—The town of Sonora is on the western slope of the Sierra Nevada, in Tuolumne county, thirty-six miles southeast of Milton, the terminus of a branch of the Southern Pacific Railroad, and about a hundred miles due east of San Francisco. Manganese has been found two miles north of the town on the land of William S. Macomber.

This locality is surrounded by some of the earliest of the once most productive placer gold diggings in California, though at present mining operations have greatly diminished. The manganese occurs in the forms of oxide and of silicate (rhodonite), in a deposit between a green porphyry and a schistose rock of the same color. These rocks dip vertically, or almost so, and rise in a somewhat abrupt hill, having withstood the disintegrating agencies which have worn the surrounding limestone down to a lower level. To the north and south of the hill are areas of white or gray crystalline limestone and of slate.

The schist borders the ore deposits on the south and is a green material of more or less chloritic or micaceous nature, either fine and granular, or coarse and showing a laminated structure. The same rock and also a gray or brown schist are found elsewhere in the hill. The porphyry consists of a dark green matrix with white feldspar crystals, and frequently has a granular structure. It borders the ore deposit on the north, and also occurs on other parts of the hill. It has the appearance, externally, of an igneous material, but may possibly represent a metamorphosed sedimentary deposit*. Professor J. D. Whitney,† in speaking of metamorphism in the auriferous slate formation, in the same region as the limestone, says: "Besides the slate, there are sandstones in various stages of alteration; but they have almost everywhere been highly metamorphosed since their deposition. They frequently pass into dioritic or trappean varieties, which it is difficult to distinguish from the really intrusive or eruptive masses. They also assume a porphyritic structure, appearing in various forms of horn-

* The time available for the examination of this property did not permit an investigation of the relation of this rock to those in the vicinity, and therefore nothing more definite can be stated concerning it.

† Geological Survey of California, 1865, Vol. I., Geology, p. 282.

blende-porphyry, and passing into compact hornblende-rock, or amphibolite. Serpentine is also one of the forms of metamorphism of the rocks of the auriferous slate series, and it occurs in large masses in Tuolumne, as well as all the other mining counties." The geologic age of the limestone belt of the Sierra, of which the region in question forms a part, is supposed by Professor Whitney to be probably Carboniferous.*

The rocks strike in a general east and west direction, and the ore deposit follows the same general strike, though in some places it appears to bear a little to the north of west, possibly on account of a flexure in the rocks. Its outcrop is seen in only a few places, on account of the heavy covering of soil. Two small pits have been sunk on it, one to a depth of thirty feet, and the other to eighteen feet. They are now mostly filled up, but it is said that at the bottoms of them the ore body varied from nine to twelve feet in thickness. The ore is composed of a mixture of the oxide and a beautiful pink rhodonite and is associated with pure quartz.

The rhodonite is a pink, translucent mineral with a finely granular structure and a hardness of about 6. The oxide of manganese varies from a hard, compact, siliceous, black material to a soft, black mass of the consistency of talc, and sometimes has the same granular structure as the rhodonite. Both the oxide and rhodonite are either intimately mixed or in contiguous but distinct masses. They always blend into one another, however, and wherever found the oxide occupies the most exposed positions, surrounding masses, or enclosing small kernels of rhodonite. To the depth that the shafts have been sunk, the oxide composes the larger part of the ore, but almost every mass of the material seen on the dump contains a kernel of rhodonite. There seems to be no doubt that all the oxide has come from the oxidation of the rhodonite, and that at a certain depth the whole mass would be found to merge into that mineral.

According to present market standards, rhodonite is of no value as a source of manganese on account of its high per-

* Geological Survey of California, 1865, Vol. I., Geology, pp. 328-329.

centage of silica, nor can it be used as an oxidizing material for chemical purposes as it contains no peroxide of manganese, though the oxidized part of the deposit contains small quantities of that ingredient. Rhodonite is used, however, for cutting into gems, and the beautiful pink color of the Sonora mineral would permit its use for this purpose if it were mined at a depth sufficient to obtain it unblemished by the black oxidation product that stains it on the surface. Rhodonite has also been used for glazing pottery, as a flux in iron furnaces, and for other purposes.

Columbia.—The town of Columbia is in Tuolumne county, about six miles north of Sonora. Small quantities of manganese ore have been found in the auriferous gravel in the neighborhood. This region, just as the vicinity of Sonora and elsewhere in eastern Tuolumne county, was the seat of extensive placer workings during the early days of California gold mining. Now many of the placer deposits have been exhausted, and the working of others has been curtailed by the law restricting hydraulic mining. But the evidence of the former industry is seen in the large heaps of gravel and the areas of bare rock stripped of their original covering.

The rocks are mostly limestone and slate, striking in a general east and west direction and dipping at steep angles of from 45° to 90°. The edge of the slate often forms comparatively continuous ridges; but the more easily eroded limestone occupies the valleys and flats and is often covered by auriferous gravel. Where seen in the old diggings it forms series of jagged and irregular knobs, often of fantastic shapes, following the lines of strike of the formation. In the auriferous gravel of this region, nodules of manganese ore from one to six inches in diameter are frequently found. The ore is in the form of oxide, is of a black color, hard, and massive, sometimes granular, and is in kidney-shaped and mammillary masses. It has probably weathered out of the rocks of the region and collected in the gravel. It occurs on Knapp's ranch, on the outskirts of Columbia, and also in many other places. It is not in sufficient quantity to be of any commercial value, but is mentioned here

as this district is often referred to as a manganese locality. Patches of an earthy, black wad are also frequently seen in cavities in the limestone, and are probably due to the concentration of small quantities of manganese during the decomposition of that rock.

One mile east of Columbia manganese ore is seen in place in a shaly slate. The ore is in the oxide form, is granular in structure, and is associated with transparent quartz. The deposit is mostly obscured by soil, so that its mode of occurrence cannot be made out, but a small prospect hole sunk on it shows it to be from one to two feet in width. It probably represents a limited lenticular deposit in the slate. The latter is of a rusty gray color, strikes east and west, dips almost vertically, and is interbedded in the limestone of the region.

Cape Horn.—The name Cape Horn is given to a rugged and almost vertical cliff several hundred feet in height, which forms the northern side of the north fork of the American River, two miles east of the town of Colfax in Placer county. The river rises in the main range of the Sierra Nevada, to the east of the town of Colfax, and flows thence southwest into the Sacramento River. In Placer county, which it intersects longitudinally, it has cut a succession of deep canyons of which the locality in question forms a part. In the face of the cliff at Cape Horn are exposed a series of slaty and schistose strata, frequently micaceous and containing numerous veins and lenticular layers of quartz. The rocks strike in a general northwest direction, and dip almost vertically, sometimes with a slight inclination to the southwest. Manganese is seen in many places near the base of the hill, and occurs in the form of black oxide, in thin seams from a sixteenth to an eighth of an inch in thickness. It often forms a network of thin veins, but the quantity of ore so far as yet discovered, is very limited, and of no commercial importance.

CHAPTER XX.

THE MANGANESE DEPOSITS OF CANADA.

LOCATION OF THE DEPOSITS.

Manganese ores have been found in many parts of Canada, but the workable deposits, so far as yet known, exist only in the provinces of New Brunswick and Nova Scotia, and even there they are mostly confined to the area of the Lower Carboniferous rocks. Small quantities have been found in both older and younger rocks, but attempts to work them as a source of manganese have so far proved unsuccessful. Most of the deposits that have been worked are either directly on, or within a few miles of the shores of the Bay of Fundy or of its eastern extremities, known as Minas Basin and Chignecto Bay. Similar ores, however, are also found on the Atlantic coast of Nova Scotia and in Cape Breton.

HISTORY OF MANGANESE MINING IN CANADA.

The history of manganese mining in Canada has already been given in the general description of the industry in the United States and Canada in chapter III., but the part pertaining especially to Canada is summarized here.

Manganese was mined in Hants county, Nova Scotia, as early as 1861, but the first systematic work was done at the Tenny Cape, in that county, in 1862, under the management of John Browne. In 1864 the mine at Markhamville, New Brunswick, was opened under the management of Major A. Markham, and has been worked almost continuously ever since. This property has yielded over half the total Canadian production of manganese, and under the management of Major Markham has been for many years past, and is still, the leading producer of Canada.

Up to 1890 its total output is said to have been nearly 40,000 tons. Next to the Markhamville mine the Tenny Cape mine has probably produced more than any other in Canada, its total output up to the end of 1890 having probably been over 3,000 tons.

Besides these two mines, many others in both New Brunswick and Nova Scotia have been opened up at various times, and some of them are being worked at present. Among those in New Brunswick are the Quaco Head, Jordan Mountain, Glebe, and Shepody Mountain properties, besides several others. The Quaco Head mine has been worked intermittently for a number of years, and is at present being operated by the Brunswick Manganese Company. Among the other localities in Nova Scotia, manganese has been mined at Cheverie, Walton, Onslow Mountain, and elsewhere. At Loch Lomond, Cape Breton, manganese mining was begun in 1881 by E. T. Moseley, and has been carried on intermittently ever since.

Probably 50,000 tons would more than include the total production of manganese ore in Canada up to December 31, 1890. The detailed statistics of production, exports, and imports for both New Brunswick and Nova Scotia are given in chapter III., pages 70-73.

THE GEOLOGIC RELATIONS OF THE MANGANESE DEPOSITS.

The most important of the manganese deposits of New Brunswick and Nova Scotia occur in the Lower Carboniferous limestone or the associated strata. The exact stratigraphic relation of the rock with which the ores are associated in some of the different parts of the region is not in every case entirely clear, but with the exception of certain localities to be mentioned later in this chapter, all the deposits occur within the Lower Carboniferous series. The position of the manganese-bearing limestone formation in the Carboniferous system is represented in group 4 in the following section by Sir William Dawson: *

"When fully developed, the whole Carboniferous series

* Acadian Geology, third edition, 1878, p. 129.

may be arranged in the following subordinate groups or formations, the limits of which are, however, in most cases not clearly defined:

"(1). *The Upper Coal Formation*, containing coal formation plants, but not productive coals.

"(2). *The Middle Coal Formation*, or coal formation proper, containing the productive coal-beds.

"(3). *The Millstone-grit Series*, represented in Nova Scotia by red and gray sandstone, shale, and conglomerate, with a few fossil plants and thin coal seams, not productive.

"(4). *The Carboniferous Limestone*, with the associated sandstones, marls, gypsum, etc., and holding marine fossils, recognized by all paleontologists who have examined them as Carboniferous.

"(5). *The Lower Coal Measures*, holding some, but not all, of the fossils of the Middle Coal formation, and thin coals, not productive; but differing both in flora and fauna from the Upper Devonian, which they overlie unconformably."

Among the most noticeable features of the Lower Carboniferous rocks in the Bay of Fundy basin are the large deposits of gypsum and anhydrite which exist in group 4 of the above section. These are interbedded with the other rocks and in some places overlie the manganese-bearing limestone. Their possible relation to, and effect on the manganese deposits are further discussed at the end of this chapter.

The geologic structure of the basin of the Bay of Fundy, in which most of the manganese deposits occur, is considerably complicated on account of the disturbances to which it has been subjected at different geologic times. Sir William Dawson, however, in his Acadian Geology, has given valuable information on the geology and resources of the region. In the New Brunswick part of it the geology has been further worked out by G. F. Matthew, L. W. Bailey and R. W. Ells, and their results are published in the

reports of the Canadian Geological Survey; while E. Gilpin, Jr., in various publications referred to later in this chapter, has given excellent descriptions of the different ore deposits of Nova Soctia and their geologic relations.

The lowermost rocks of the region in question are metamorphic and of pre-Paleozoic age. Overlying them, and covering the larger part of them are found, in different places, rocks of Cambrian, Silurian, Devonian, and Carboniferous ages, which have been greatly disturbed and are now seen in various degrees of folding. These are occasionally overlain unconformably by isolated areas of New Red Sandstone (Triassic), filling basins in their denuded surfaces. A large part of the Nova Scotia coast of the Bay of Fundy is lined with eruptive Triassic traps, and evidences of eruptive action are seen at various horizons throughout the other strata represented in the region.

The pre-Paleozoic rocks appear in scattered outcrops or in long ridges bordered by the younger strata. The Carboniferous rocks cover a large part of the region, but the Silurian also comprise considerable areas, while the Devonian and Cambrian rocks are represented by smaller exposures. The Triassic sandstone forms a broken fringe at intervals along the shore of the bay and is prominent by its characteristic red color. The rocks, however, that are of most importance to the subject under consideration are the Lower Carboniferous, and these are found over a very considerable territory both in New Brunswick and Nova Scotia. They frequently comprise large areas on the immediate coast of the Bay of Fundy, especially near its head, on the shores of Minsas Basin and Chignecto Bay; and they also play a prominent part in the stratigraphy of the interior. Small quantities of manganese ore have also been found in pre-Paleozoic, Cambro-Silurian, Coal Measure, Triassic, and the other rocks and will be further mentioned later in this chapter.

THE MANGANESE ORES.

Mineralogical forms of the ores.—The manganese ores of

New Brunswick and Nova Scotia represent oxides of the metal, and are mostly in the forms of pyrolusite, manganite, psilomelane, and wad.

Pyrolusite, manganite, and psilomelane.—Pyrolusite, manganite, and psilomelane often occur together, blending into each other and varying considerably in relative amounts. Sometimes, as at Tenny Cape, pyrolusite is the predominating mineral, though smaller quantities of the others exist. At Cheverie and Walton manganite is common, while at Markhamville pyrolusite and manganite are both found in considerable quantities. Psilomelane is frequently associated in greater or less quantities with the other oxides.

The character of these ores varies slightly in different places, but they conform, in a general way, to the descriptions of manganese ores given in chapter V. The pyrolusite occurs in nests of fibrous, orthorhombic prisms, often radiating from a center or encrusting masses of psilomelane. Sometimes the fibres are long and slender with perfect terminations, sometimes short and more compact, or even existing as a finely granular, crystalline aggregate. The manganite is not usually in such large crystals as the pyrolusite, but often occurs in well developed prisms, markedly different from those of pyrolusite in their greater hardness. The psilomelane is in more or less nodular masses of dark steel-blue or black ore, often coated by an incrustation of radiating crystals of pyrolusite. All three varieties are frequently associated with calcite, barite, selenite, and sometimes limonite and hematite, besides other minerals in small quantities.

The analyses given below, made by Professor H. How, represent the composition of pyrolusite and manganite from Nova Scotia:

*Analysis of pyrolusite from Amherst, Nova Scotia.**

Manganese peroxide (MnO_2)	97.04
Water (H_2O)	0.61
Gangue and loss	2.35
	100.00

* H. How, London, Edinburgh and Dublin Phil. Mag., March, 1866.

The insoluble matter (gangue) was brownish-white and and most probably consisted of barytes."

*Analysis of manganite from Cheverie, Nova Scotia.**

Manganese sesquioxide (Mn_2O_3)	86.81
Water (H_2O)	10.00
Gangue	1.14
Oxide of iron, barite and loss	2.05
	100.00

It will be observed that the manganite analysis represents an impure hydrous sesquioxide of manganese, approaching, when the impurities are disregarded, the theoretical composition of manganite, Mn_2O_3, H_2O, which contains: manganese sesquioxide, 89.8; water, 10.2.

Wad.—Wad is by far the most abundant of the manganese minerals in Canada, but it is of low grade, representing a highly siliceous bog manganese, and is not used as a source of the metal. From a commercial standpoint, therefore, it cannot be termed an ore. It is occasionally used as a basis for pigments, but even for this purpose its consumption is limited. Small quantities have been mined, though but little of it has been shipped out of the provinces. It occurs in association with many of the rocks represented in the region, but is often, or even generally, a secondary product, arising from the surface decay of these rocks, and has not always been laid down in its present form with them. This is especially true of the areas of crystalline rock, where wad often occupies hollows on the surface and is the result of the decomposition of the underlying rock. Sometimes, however, especially in the younger rocks, wad occurs as a bed laid down at the same time as the enclosing strata. It is usually a more or less porous, earthy material of a brown or black color, either in the form of nodules in clay or as a continuous bed, sometimes several feet in thickness and exceedingly variable in composition. It contains from 10 per cent to over 30 per cent of manganese and sometimes over 25 per cent of water. It is always associated with more or less iron.

* London, Edinburgh and Dublin, Phil. Mag., March, 1866.

Large quantities of wad are stated by R. Chalmers,* to exist in the gravel near the Government House, Fredericton, N. B.; also at Queensbury, York county, and at Lincoln, Sunbury county. E. Gilpin, Jr., reports† its existence in Nova Scotia at Chester, Parrsborough, Jeddore, Beech Hill, Lochaber, Tracadie, Louisburg, Sydney, and on Boularderie Island; also‡ at Ship Harbour, St. Margaret's Bay, Shelburne, La Have, Springhill, and in Pictou and Antigonishe counties. Hugh Fletcher§ reports it as existing on the road to Goshen from the foot of Lochaber, on the telegraph road near Afton, in Pomquet River, in Southerland's Brook immediately above the East River of St. Mary's, and on the hill south of the railway west of Piedmont station. Wad has also been found in many places in the eastern townships in the Province of Quebec, especially in the townships of Bolton and Stanstead. It also occurs in the township of Tring, in the seignories of Aubert Gallion, St. Mary, St. Anne de la Pocatière, Cacouna, and many other places.‖ These localities are only a part of the many that are known, but they will serve to show the general distribution of wad in Canada. The following analysis by Mr. Gilpin shows the composition of a characteristic specimen of wad from Boularderie Island, Cape Breton.

Analysis of wad from Boularderie Island, Cape Breton.¶

Manganese peroxide (MnO_2)...	44.33
Ferric oxide (Fe_2O_3).....	35.50
Insoluble matter.....	10.00
Manganese.....	28.01
Iron.....	24.85

Commercial values of the ores.—The uses of the man-

* Geological and Natural History Survey and Museum of Canada, Alfred R. C. Selwyn, Director, Report of Progress, 1882-3-4, p. 47, G. G.

† Mines and Mineral Lands of Nova Scotia, p. 91-92.

‡ Trans. Roy. Soc., Canada, May 22, 1884, p. 7.

§ Geol. Survey of Canada, 1886, p. 118. P.

‖ Geology of Canada, 1863, p. 752.

¶ E. Gilpin, Jr., Trans. Roy. Soc., Canada, March, 1884, p. 7.

ganese ores of New Brunswick and Nova Scotia differ from the uses of the larger part of the manganese ores of the United States, in that the former are devoted mostly to chemical purposes, while the latter are largely consumed in the manufacture of spiegeleisen and ferro-manganese.

The manganese ore used for chemical purposes has a much greater value than that used for spiegeleisen and ferro-manganese. It sells for from 2 to 5 cents per pound, or from $40 to $100 per ton, according to quality, while that used for the latter purposes rarely brings over $15 per ton. The applicability of an ore for either use depends on its composition: its value for chemical purposes is based largely on its oxidizing power, that is, on the amount of oxygen, known as "available oxygen," that can be obtained from it in the ordinary processes of manufacture. The available oxygen, as explained in previous chapters,* depends on the amount of manganese peroxide in it, and therefore the market price of an ore for chemical purposes is determined by the percentage of this constituent. Pyrolusite contains a larger percentage of peroxide than any of the other manganese ores, in fact being, when pure, composed entirely of it, and therefore the value of the Canadian ores is due mostly to the large proportion of this mineral found in them. Pyrolusite is never found in a perfectly pure state in nature, however, and the very best picked ore rarely contains more than from 70 to 95 per cent of peroxide, equal to about 13 to 17 per cent of available oxygen.

Psilomelane also contains a considerable proportion of peroxide, but on account of its hardness and other peculiarities, as already explained on page 42, it is not so desirable as pyrolusite for most chemical purposes. Manganite, on the other hand, has only a small percentage of peroxide;† while wad, though it frequently contains a considerable amount, is too impure to be desirable for chemical purposes.

In the manufacture of spiegeleisen and ferro-manganese, the

* See pages 8, and 40–42.

† Manganite is a hydrous sesquioxide of manganese and, accurately speaking, contains no manganese peroxide; but what is meant here is simply the amount of available oxygen expressed in a commercial sense in terms of "peroxide." Manganite when perfectly pure contains about 9 per cent of available oxygen, equal to about 49 per cent of peroxide, but it is never found in large quantities in this degree of purity.

amount of available oxygen is not an item in the valuation of the ore. For these purposes, the three main requisites are a high percentage of manganese and a low percentage of silica and of phosphorus. Hence the manganese ores of the United States, which usually contain a smaller proportion of pyrolusite than the New Brunswick and Nova Scotia ores, but often fill all the requirements for spiegeleisen and ferro-manganese, are used for the manufacture of these materials. Small quantities, however, are sorted out and sold for chemical purposes.

At present most of the Canadian ore is used as a reagent in glass-making, in electric batteries, in the manufacture of chlorine and disinfectants, as a dryer in varnishes, and for other chemical purposes.* The use as a reagent in the manufacture of chlorine is one of the largest chemical sources of consumption of manganese, but the best grades of Canadian ores are too high priced to be employed for this purpose, their greatest value being in glass-making. For this purpose the freedom of the ore from iron is a necessary quality, and the purity of much of the Canadian manganese renders it especially well adapted for this use. (See pages 49-50.)

It is the adaptibility of the Canadian ores for the above mentioned purposes, and consequently their high price, that permits them to be worked, as they do not occur in quantities sufficient to be profitably mined as a source of spiegeleisen and ferro-manganese alone. The poorer grades of ores, however, which are mined in connection with the better ones, are shipped under the name of "furnace ore" and are sold at the regular price of ores for spiegeleisen and ferro-manganese.

The following table by Professor H. How,† shows the percentage of peroxide, and hence the value for chemical purposes, of manganese ores from various localities in Nova Scotia:

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* See chapter III.

† Nova Scotia Inst. Nat. Sci., 1865.

Manganese peroxide in Nova Scotia ores.

No.	LOCALITY.	Kind of ore.	Manganese peroxide.
1	Cumberland co	Pyrolusite.	97.04
2	Tenny Cape, Hants co	"	95.00
3	" " " "	"	92.69
4	" " " "	"	88.01
5	Douglas, Hants co	"	84.62
6	Cheverie, Hants co	Manganite	47.78
7	Halifax co	Wad	56.00

The analyses on page 506 represent the composition of manganese ores from New Brunswick and Nova Scotia. They were made by the Geological Survey of Canada and have been kindly furnished by Professor G. C. Hoffmann, Chemist and Mineralogist. The column representing "manganese" has been inserted by the writer, and was calculated from the percentages of peroxide of manganese given in the original analyses. Sample No. 5 is a hydrous sesquioxide of manganese (manganite), and therefore the percentage of manganese calculated from the amount of peroxide is too low. The same is true to a lesser degree of sample No. 3 which contains a little manganite. In the other samples, however, the percentages of manganese as calculated from the peroxide represent, for all practical purposes, very nearly the true amounts.

MODE OF OCCURRENCE OF THE MANGANESE ORES.

The manganese ores exist in the Lower Carboniferous limestone in the forms either of interbedded lenticular layers, or nests and pockets, carrying from a few pounds to several tons; or as short discontinuous veins. The limestone is generally much folded and is sometimes shattered and brecciated throughout, or pierced by intrusive masses of eruptive rock. It varies from a compact, massive, blue or gray limestone, as at Markhamville, and a highly crystalline, dark brown one, as at Loch Lomond, to a much broken, shaly dolomitic material, as in Hants county, Nova Scotia. The bedded condition of the ores is most marked in the unbroken massive and crystalline rock and

Analyses of manganese ores from New Brunswick and Nova Scotia.

No.	LOCALITY.	NATURE OF THE ORE.	Manganese peroxide.	Ferric oxide.	Insoluble matter, silica, etc.	Water of combination.	Moisture.	Manganese.	Iron.	Analyzed by
1	Gowland Mt., Elgin, N.B	Psilomelane with a little pyrolusite	50.21	3.06	33.78			31.73	2.14	F. D. Adams.
2	Loch Lomond, Cape Breton	Pyrolusite	91 84	0.12	2.91			58.03	0.08	" " "
3	Mira Hills, Cape Breton	Pyrolusite with a little manganite	81.52					51.51		" " "
4	" " " " "	Pyrolusite	88.98	0.21				56.23	0.14	" " "
5	Amherst I., Magdalen Isls	Manganite	45 61				0.10	28.82		" " "
6	Big Harbour, Cape Breton	Bog manganese	25.42			33.52		16.06		" " "
7	Lewis Bay, Cape Breton	Bog manganese	44.99		12.25			28.43		E. B. Kenrick.

(1) Geological Survey of Canada, Report of Progress, 1885, p. 20 M.
(2) " " " " " " " 1880-81-82, p. 12 H.
(3) " " " " " " " 1879-80-81, p. 17 H.
(4) " " " " " " " " " " " " " "
(5) " " " " " " " " " " " " " "
(6) " " " " " " " 1880-81-82, p. 12 H.
(7) " " " " " " " 1886, p. 19 T.

the vein character in the brecciated material. Considerable quantities of ore have also been taken from the residual clay which sometimes overlies the decayed surface of the limestone and contains the ore that has weathered out of it.

The mode of occurrence of the ores and the nature of the associated rocks vary so much in different localities, that further generalizations cannot be given here. For more definite details the reader is referred to the descriptions of individual properties given in this chapter.

THE MANGANESE DEPOSITS OF NEW BRUNSWICK.

General features.—The manganese deposits of New Brunswick are mostly in the watershed of the Bay of Fundy, in some places immediately on the coast, in others from fifteen to twenty-five miles inland.*

In the various ore-bearing localities the Lower Carboniferous rocks very often directly overlie those of pre-Cambrian age. The deposits of manganese ore occur in association with the limestone of the former, sometimes near the contact and sometimes separated from it by intervening local areas of conglomerate and other rocks. The limestone is generally more or less magnesian, and is a compact, massive, blue or gray rock, containing veins of crystalline calcite, and sometimes showing a semi-crystalline structure.

The Markhamville mine.—The Markhamville mine is situated at the village of Markhamville, near the head of the Hammond River, in Kings county, about forty miles northeast of St. John, about fifteen miles north of the shore of the Bay of Fundy, and about eight miles south of Sussex, on the Intercolonial Railway. The existence of manganese was noted at the head waters of the Hammond River many years ago by Mr. George F. Matthew, of the Geological Survey of Canada, but the property was first opened about 1864, under the management of Major A. Markham. Major Markham was the first to attempt to develop in a systematic manner the manganese deposits of

* Other deposits, in geologic relations different from those here described, occur in the northern part of the province and will be mentioned later in this chapter.

this province, and it is due to his energy and perseverence that the ores have been introduced into the market.

The ore occurs either as crystalline pyrolusite and manganite, or in a compact, massive, nodular or bedded form, sometimes containing psilomelane.

The ore-bearing limestone is generally of a gray color, but at times is pink or buff, and is associated with shaly strata. It contains veins of crystalline calcite, in which masses of pyrolusite are frequently found, but the principal ore deposits are lenticular bodies interstratified with the limestone. These occur either as irregular pockets, or as flat layers, more or less continuous for considerable distances, and becoming thin and thick at intervals. In some places such deposits widen out into pockets from which several hundred tons of ore have been taken, and in one opening 3,000 tons are said to have been mined. Though in places the pockets do not always adhere strictly to the bedding of the rock, yet in a general way they follow it. Sometimes veins and pockets cut directly across the bedding, but these are generally smaller than the others and are probably due to a secondary chemical action by which they have been derived from the bedded ores.

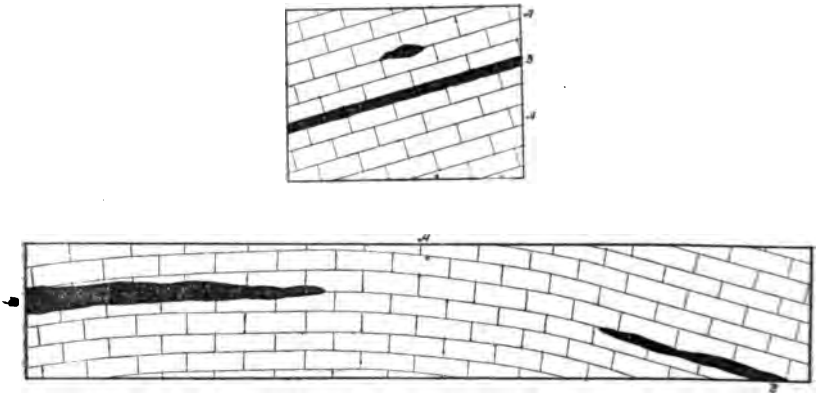

Figure 40. *Sections in openings at the Markhamville mine, New Brunswick, showing the mode of occurrence of the manganese ore.*

A. Limestone.

B. Manganese ore.

Scale: 1 inch—8 feet.

The two sections in figure 40 represent exposures of ore in

openings on the property, and illustrate on a small scale the characteristic modes of occurrence, though very much larger bodies of ore than those here shown have been worked. The smaller section shows an interstratified lenticular layer of ore through the center and an irregular, isolated pocket lying in another plane of stratification above. The larger section shows two lenticular pockets following the same line of stratification in the limestone, but separated by a barren area.

The surface of the limestone has often been decomposed and a red residual clay, frequently mixed with surface gravel, has collected in considerable quantities. The ore that was originally in the part of the limestone which has decayed, is now found buried in the clay; and therefore deposits of ore-bearing clay or gravel, overlying the partly decomposed surface of the limestone, are of frequent occurrence. Such deposits are rarely more than from eight to twenty feet in thickness, but the ore in them is cheaply worked and they have supplied a large part of the output of the Markhamville mine. Frequently the decomposition of the limestone has spread downward more rapidly along the outcrop of a body of ore than elsewhere, causing somewhat abrupt hollows filled with residual clay and manganese ore, and containing in the bottom the outcrop of the ore in situ in the rock.

Not only has decomposition taken place on the surface, but it has also gone on to a considerable extent underground, frequently causing subterranean cavities and passages. When these have intersected bodies of manganese the floors are covered with loose fragments of ore, brought there in the same way as that in the residual clay on the surface. Kidney-shaped masses of glossy, black limonite are frequently found with the cave deposits, and these also have doubtless come from the limestone.

Figure 41 represents a section exposed in a surface pit. It shows the decayed surface of the limestone and the overlying residual material, with fragments of ore that have weathered out of the rock. It will be observed that the body of ore in the limestone has been partly freed from the rock by decay, and that the fragments have become enveloped in the overly-

ing clay. It will also be noticed that the decay of the rock has reached deeper where there is ore than where there is none.*

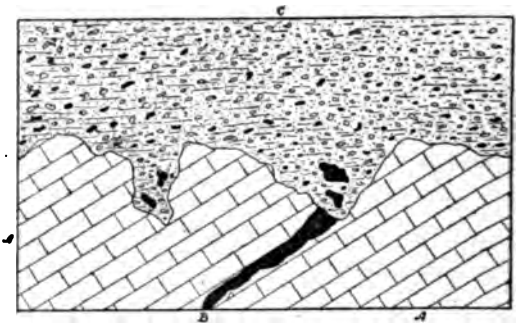

Figure 41. *Section at the Markhamville mine, New Brunswick, showing the decay of the ore-bearing limestone and the formation of residual ore-bearing clay.*

A. Limestone.

B. Manganese ore.

C. Manganese-bearing clay.

Scale: 1 inch—10 feet.

Though a large amount of manganese has been taken from the surface clay beds and the caves, yet the deposits of ore in the limestone have also been extensively worked, and in many places the rock is honeycombed with a network of shafts and drifts, following the erratic courses of the ore bodies in all their intricacies.

The thickness of the limestone varies considerably: in one of the pits a depth of twelve feet was found, and a diamond drill boring in another part of the property showed a thickness of fifty-five feet. Probably a greater thickness will be found elsewhere. The bed is much disturbed and is folded into small anticlines and synclines, but at Markhamville it has a general dip to the northwest and a strike of northeast and southwest. In many places it contains fossils and sometimes the carbonate of lime of these has been partly replaced by manganese, which has subsequently been oxidized and now exists as a black, more or less calcareous mass.

The Hammond River rises near Markhamville and flows southwest, parallel to the coast of the Bay of Fundy, until it finally turns south and empties into the bay about eight miles

* This rapidity of decay of the ore-bearing part of the rock is further discussed in the final chapter of this report.

southeast of St. John. In the region of Markhamville, and for some miles down the river, the Lower Carboniferous limestone occupies the center of the valley; but it is only locally that manganese occurs in it, and only at the Markhamville mine that it has yet been found in large quantities.

The limestone area is bordered on the south by a range of hills which forms the southern barrier of the Hammond River valley. According to information kindly furnished by Mr. G. F. Matthew, of the Geological Survey of Canada, these hills are composed largely of the underlying pre-Cambrian rocks, and the Carboniferous rocks dip away from them. To the north of the river the limestone is cut off in many places by an abrupt escarpment of Carboniferous conglomerate which, according to the same authority, probably belongs above the manganese-bearing limestone.

The ore from this mine is mostly used for chemical purposes. It is prepared for market by crushing, washing, and sizing with screens. Certain quantities of the lower grades, however, are shipped, without previous preparation, under the name of "furnace ore," and are used in the manufacture of spiegeleisen and ferromanganese.

The Quaco Head mine.—The Quaco Head mine is situated on Quaco Head, on the north shore of the Bay of Fundy, one mile south of the town of St. Martin's, about thirty miles east of St. John, and twenty-four miles south of Markhamville. It forms a bold headland protruding into the bay for almost a mile and forming the southern barrier of Quaco harbor. A branch railway connects St. Martin's with Hampton, on the Intercolonial Railway, which runs thence to St. John, making the total distance from Quaco Head to St. John, by rail, fifty-one miles. The mine has been worked at several different times, and up to April, 1889, several hundred tons of ore are said to have been taken out. The property was acquired in 1889 by the Brunswick Manganese Company.

The manganese is sometimes crystalline, representing pyrolusite and possibly also manganite, while at other times it is hard and massive possibly representing psilomelane, and still again it

is in a porous, honeycombed form. These ores are found in Lower Carboniferous shales and limestones, associated with a large conglomerate bed.

The rocks are greatly disturbed and have been much shattered and broken by igneous intrusions. They now stand at steep angles, sometimes almost vertically, exposing, in different parts of the headland, areas of limestone, shale, and coarse conglomerate. Masses of igneous material protrude into these beds at different points, and on either side of the headland are beds of Triassic sandstone and fine conglomerate* lying unconformably on the upturned edges of the older rocks.

The general section in figure 42 shows the relation of the different rocks. It will be seen that the conglomerate forms the highest part of the headland, that to the northeast of it are successively the shale, limestone, and an igneous intrusion, and that the Triassic sandstone occupies both sides of the headland.

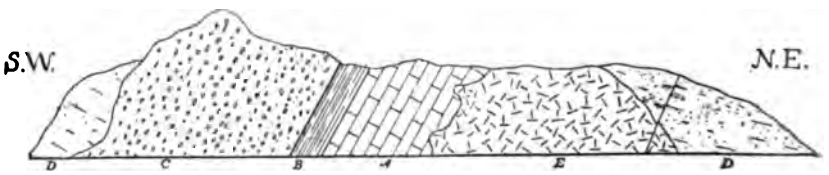

Figure 42. *Section on Quaco Head, New Brunswick.*
A. Limestone.
B. Shale.
C. Conglomerate.
D. Triassic sandstone.
Horizontal scale: 1 inch=¼ of a mile. Vertical scale: 1 inch=100 feet.

The manganese occurs as nodules and irregular, discontinuous veins, in both the shale and the limestone, though the larger quantities are in the former. The nodules vary from a fraction of an inch to several inches in diameter, and the thickness of the veins is equally variable. The disturbed character of the rocks renders it somewhat difficult to determine the thickness of the main ore-bearing bed, but it is probably not over thirty feet, though smaller quantities of manganese are found in the rocks on either side. The ore is scattered through this thickness

* These beds are designated as Triassic on the map accompanying Sir William Dawson's Acadian Geology.

in very variable quantities. The amount of commercially available ore at Quaco Head is small.

The igneous rock is a hard, light gray, close grained material of a texture somewhat like trap. The limestone is like that of Markhamville, though it is much reddened at the contact with the igneous rock. The conglomerate bed is composed of coarse pebbles of metamorphic rocks. It dips steeply to the south and forms a bold bluff, on which the lighthouse of Quaco Head is situated. The sandstones and conglomerates at each end of the section, are of a brick-red color and vary from coarse sandstone to a fine conglomerate, with pebbles from a quarter of an inch to one inch in diameter, both sand and pebbles being composed of white quartz stained by a ferruginous cement. Sometimes these beds contain small, irregular seams or nodules of manganese ore which, however, are in very limited quantity, and have doubtless been derived, during the deposition of the beds, from the erosion of the Lower Carboniferous rocks.

The accompanying analyses by Dr. A. M. Comey, show the composition of the better grades of ore from Quaco Head:

*Analyses of manganese ore from Quaco Head, New Brunswick.**

CONSTITUENTS.	Compact variety.	Porous variety.
Manganese peroxide (pyrolusite)...	71.54	65.00
Ferric oxide.....	2.19	1.75
Calcium	trace	trace
Phosphorus.....	0.02	0.04
Sulphur.....	0.00	0.00
Insoluble silicates.....	8.37	6.66
Manganese	58.20	57.15
Iron.....	1.53	1.23

The ore-bearing rocks can be traced back on the promontory at intervals for almost a mile, to a place where an opening has

* Analyses by A. M. Comey, given in the report of C. L. Whittle to the Brunswick Manganese Company, 1889, p. 12.

been made on the farm of Mr. Molaskey. On the north side of the head, small scattered nodules of manganese ore are found in the gravel drift that lines that part of Quaco Harbor and extends inland over the Lower Carboniferous rocks. They have, doubtless, been derived from the latter rocks during deposition of the gravel, in the same way that the red sandstone just mentioned obtained its manganese contents at an earlier date.

The Glebe mine.—The Glebe mine is situated three miles north-northeast from Markhamville and about seven miles from the Intercolonial Railway at Sussex.

The ore is found in a limestone resembling that at Markhamville, though it is much less disturbed than at that place and dips gently to the west. The manganese ore occurs in the limestone in nodules and thin layers, frequently associated with calcite and following the general direction of the stratification. Several shafts and tunnels have been made, the deepest shaft being 85 feet.

Other localities in the Lower Carboniferous rocks of New Brunswick.—Besides the properties already described manganese has been found in Lower Carboniferous rocks in several other places in the neighborhood of the Bay of Fundy, in New Brunswick. Very little work has been done on them, however, and many have not even been prospected. The following list of localities is given by Messrs. Bailey, Matthew, and Ells.* In some of the places the geologic position of the deposits is uncertain, but most of them are in Lower Carboniferous rocks:

"Shepody Mountain.—Deposits near the contact of pre-Cambrian chloritic slates and Lower Carboniferous conglomerates, worked in former years quite extensively but of late nothing has been done.

"East Side of Salisbury Bay.—Deposit near the contact of Triassic sandstone and Lower Carboniferous rocks, worked some years ago by the company owning the Markhamville mine, but shortly abandoned.

"Hopewell Corner.—Deposit near the contact of Millstone

* Geological Survey of Canada, 1878-79, p. 24 D.

Grit and Lower Carboniferous; about one mile west of Hopewell Corner. Soon exhausted.

"Hillsdale.—About fifteen miles southeast from Elgin Corner. * * *"

"Petitcodiac.—About two miles northwest from Petitcodiac station. Near the contact of Lower Carboniferous limestone and gypsum; vein only about one inch exposed thickness.

"Jordan Mountain.—Near the contact of Lower Carboniferous sediments with the pre-Cambrian of the mountain. * * *"

"Henry's Lake.—Surface indications reported, but deposit not located."

Localities in New Brunswick in rocks other than Lower Carboniferous.—Though the principal manganese deposits in New Brunswick are in Lower Carboniferous rocks, small quantities of ore have been found in rocks of other ages. Mr. G. F. Matthew, of the Geological Survey of Canada, has observed small quantities of manganese in the pre-Cambrian hills between Markhamville and Quaco.

At Tête à Gauche Falls, eight miles from the town of Bathurst, in New Brunswick, nodules of manganese ore occur in red and black slates of Cambro-Silurian age.* This locality was worked a number of years ago and a certain quantity of the ore is said to have been shipped. The ore was freed from the slate by crushing in a stamp mill and subsequently washing. The property is now idle. Many of the Cambro-Silurian rocks of this section are said by Dr. Ells to be deeply stained by manganese, but no extensive beds of ore have been found.

Small quantities of manganese ore have been found in the Triassic sandstone of New Brunswick, and have been mentioned at Quaco Head on page 513.

THE MANGANESE DEPOSITS OF NOVA SCOTIA.—*General features.*

The manganese ores of Nova Scotia, as in New Brunswick, are found mostly in the marine limestone formation of the Lower Carboniferous series.† The nature of the ore-bearing

* R. W. Ells, Geological Survey of Canada, 1879-80, p. 45 D.

† The exact stratigraphic relation of the ore-bearing limestones in New Brunswick and in different parts of Nova Scotia is as yet somewhat uncertain, but they all belong to the same series of rocks.

limestone, however, differs considerably in different places, being sometimes in a highly brecciated condition as in Hants county, and at other times highly crystalline as at Loch Lomond in Cape Breton. The ores have been worked in a number of places, especially on the shores of Minas Basin and to a smaller extent in Cape Breton.

THE MANGANESE DEPOSITS OF NOVA SCOTIA.—*Minas Basin.*

General features.—Minas Basin is the northeasterly end of the Bay of Fundy; and the larger part of the manganese mining in Nova Scotia has been done in its neighborhood, principally in Hants county on its southern shore and to a lesser degree in Colchester county on the east. The general structure of the region on the coast of Hants county is a series of east and west folds with subordinate transverse disturbances*. The limestone formation skirts the southern shore of Minas Basin from the Shubenacadie River on the east, to the estuary of the Avon on the west, a distance of about forty miles. In this belt of country most of the manganese localities that have been worked in Nova Scotia are found, among which are the Tenny Cape, Walton, and Cheverie properties. In fact, more or less signs of manganese occur almost continuously along the outcrop of this formation, but it is only locally that the ore is in workable quantities. The limestone overlies a series of sandstones, shales, conglomerates, and grits, which crop out in numerous places along the bay.

The ore-bearing limestone is probably several hundred feet in thickness in its largest development, and is overlain by the great gypsum beds of the region. The rocks dip away from the shore towards the interior, and the ore-bearing formation soon disappears under the gypsum and other beds, to reappear again in the southern part of the county, south of Windsor. Mr. E. Gilpin, Jr., has recognized in this manganese-bearing limestone a formation distinct in character from the associated rocks, and Sir William Dawson has followed his arrangement and makes it a separate subdivision, though it has no distinguishing fossils. †

* E. Gilpin, Jr., Trans. Roy. Soc. Canada, May 22, 1884, p. 9.

† Acadian Geology, third edition, 1878, supplements to second edition, p. 51.

Mr Gilpin,* in speaking of the Lower Carboniferous marine limestone in Nova Scotia, says: "This horizon forms one of the widest spread, and most strongly marked of the Carboniferous period. It is met in King's county, in Hants, Cumberland, Colchester, Pictou, and Antigonishe, and in the four counties of the Island of Cape Breton. The measures of this division, comprising sandstones, shales, grits, and limestones, with beds of gypsum and marl, sometimes rest directly on the pre-Carboniferous strata, and at many points are separated from them by the lower, or false coal-measures, or by beds of conglomerate, according to the conditions of the period of accumulation. The limestones and gypsums occur, apparently, at no fixed horizon in this division. Dr. Dawson, in his 'Acadian Geology,' has divided the limestones into five groups, characterized respectively, so far as the subject has received attention, by a predominance of certain fossil forms. In his supplement to the second edition, he proposes to subdivide the lowest group by distinguishing a certain manganiferous limestone, which appears at many points to form the basis of the limestone formation, strictly so called. This limestone at Salmon River, Cape Breton county, Springville and New Laing, Pictou county, Chester, Maitland, Tenny Cape, Windsor and Onslow, seems to underlie the gypsum beds, and generally to be associated with the manganese. The following analyses by the writer show the character of some of these limestones:

CONSTITUENTS.	Springville, Pictou co.	Springville, Pictou co.	Tenny Cape.	Salmon River C. B.
Lime carbonate	83.42	55.28	49.81	49.269
Iron carbonate	1.20	24.11	2.56	4.044
Magnesia carbonate	10.32	10.15	35.44	28.034
Manganese carbonate	1.38	1.83	4.58 †	14.586
Insoluble matter	4.85	5.00	8.06	1.298
Moisture	.....	0.40	0.37	.....
	101.17	96.77	100.82	97.231

* Notes on the Manganese Ores of Nova Scotia, Trans. Roy. Soc. Canada, May 22, 1884, pp. 8-9.

† As peroxide.

"The limestone of Chester, on the Atlantic shore, presents a remnant of Lower Carboniferous measures, formerly without doubt co-extensive with those of our northern counties. The lower beds are described by the late Dr. How as compact, of a dark blue color, and consisting principally of carbonates of iron, lime, magnesia, and manganese, yielding umbers by weathering. These are the most highly magnesian and manganiferous limestones that I have yet met in the province. It is quite possible that there may be others higher in the marine limestone formation carrying notable percentages of the carbonates of these metals. In the case of the Pictou district, however, the overlying limestones, up to what may be termed the base of the millstone-grit, are decidedly non-magnesian; the inspection of a very complete set of analyses showing none carrying over four per cent of the carbonate of magnesia, and usually little more than traces of manganese."

The Tenny Cape mine.—The Tenny Cape mine was opened in 1862 under the management of John Browne and has been worked intermittently ever since. It is at present (1890) the property of Mr. J. W. Stevens.

The total production of the mine up to January 1st, 1891, was probably over 3,000 tons. Several large pits and shafts have been sunk on the property, the deepest of which is a hundred and sixty feet. A tunnel has also been run through the ore-bearing rock from the foot of the hill on which the mine is situated.

Most of the ore mined at Tenny Cape is a high grade pyrolusite, but smaller quantities of manganite and psilomelane are also found. The pyrolusite is especially valuable in glass-making on account of its freedom from iron. It is stated by Professor How* that J. Taylor and Company, assayers, of London, found the ore to contain $5.00 per ton in silver.

The manganese occurs in a much disturbed, calcareous rock, having the composition, according to Mr. Gilpin,† of a dolomitic limestone, and frequently containing strata of shale.

* H. How, London, Edinburgh and Dublin, Phil. Mag., March, 1866.

† Trans. Roy. Soc. Canada, May, 1884, pp. 8-9.

It varies from gray to brown in color, is much broken and forms a breccia, sometimes carrying large masses of the original bed. The breccia consists of comparatively small fragments closely packed together, while the large masses of unbroken rock exist in it as "horses." The deposit seems to be the re-cemented remains of a single, greatly shattered bed. It is probably over two hundred and fifty feet in thickness, and dips steeply to the south and southwest. It lies on an unbroken massive sandstone, or quartzite, which dips at the same angle and forms the floor of the ore-bearing rock. Sometimes the two beds are separated by a layer of hard, red clay from two to four inches in thickness.

The exposures of these rocks occur on the south slope of a hill, at the foot of which the breccia disappears under a low hollow covered with debris. A well in the hollow is said to have reached gypsum, and fragments of that material are found in the soil. It is also found in situ and worked a short distance still further south, so that there can be but little doubt that the breccia dips under the gypsum.

The ore occurs both in the breccia and in the large masses of solid rock, in the form of flat nodules, seams, and pockets, the last being either isolated or connected by thin leads of ore. The seams vary in thickness, sometimes thinning to less than an inch, and at other times widening out to six inches or more. The pockets are from one inch to several feet in diameter. Some of them are said to have produced as much as three hundred tons of ore, and occasionally more. The following extract, quoted by Dr. How * from a letter to him from John Browne, the former manager of the mine, describes a typical occurrence of the larger bodies of ore: "On the south side of the ridge a large open cut was brought in, running nearly north and south, in which was discovered the first large deposit, at a depth of only fifteen feet from the surface. It extended some twelve fathoms in length, varying in thickness from fourteen feet to as little as six inches. From this pocket we took from

* H. How, Notes on the Economic Mineralogy of Nova Scotia, Part II., Ores of Manganese and their Uses, Proceed. and Trans. Nova Scotia Inst. Nat. Sci., 1864-5, p. 131.

one hundred and twenty to one hundred and thirty tons, leaving nothing in the bottom but a few small veins. Upon these we sank our shaft, and at a depth of fifteen feet, making in all thirty feet from surface, we intersected pocket No. 2, immediately underneath the first deposit and making in the same direction. The manganese in the second pocket is of far superior quality to that found nearer the surface, and we have returned from it some hundred and eighty tons."

The ore is sometimes associated with considerable quantities of calcite and with fibrous crystals of selenite, as well as with barite and glossy black masses of limonite. In some places, however, it is almost entirely free from foreign accompaniments. The ore is irregularly scattered through the bed: sometimes it is entirely absent and at other times the shale and limestone are cut by a network of ore-bearing veins, with feeders and side pockets running off at intervals. The veins are most regular in a large body of solid shale, where they occupy indiscriminately joints and lines of bedding, and possibly lines of faulting; while in the breccia they take a meandering course among the component masses of the bed, and often completely encircle them, making the ore very uncertain in extent and much more difficult to mine than it is in the shale. Deposits of this form, however, are to be expected in a rock of this kind, since the formation of the cavities that the ore now occupies was largely dependent upon the position and shape of the component rock masses. The breccia is known as the "soft rock," and the veins run from it into the large mass of shale and from the shale into the breccia without any interruption, except in the regularity of the deposits.

The accompanying sections in figure 43 show the mode of occurrence of the ore in the shale. It will be seen that it exists both as flat layers in bedding planes and also as veins running in various directions across the stratification. In the former case the ore is not confined absolutely to planes of bedding, but, as shown in the upper section, frequently widens out and forms irregular pockets protruding transversely to the stratification.

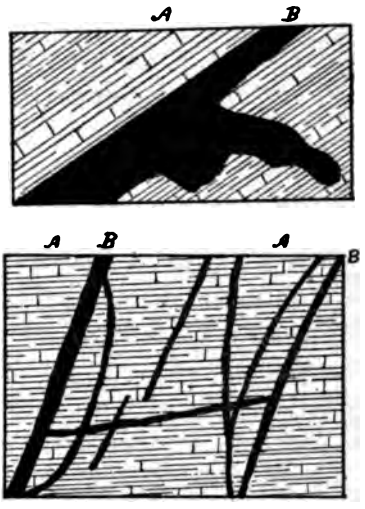

Figure 43. *Sections at the Tenny Cape mine, Nova Scotia, showing the mode of occurrence of the manganese ore.*

A. Shale.

B. Manganese ore.

Scale: 1 inch=3 feet.

Figure 44 is a section through the property in a north and south direction, and illustrates the mode of occurrence of the ore-bearing stratum as a whole, and its relation* to the underlying sandstone and overlying gypsum.

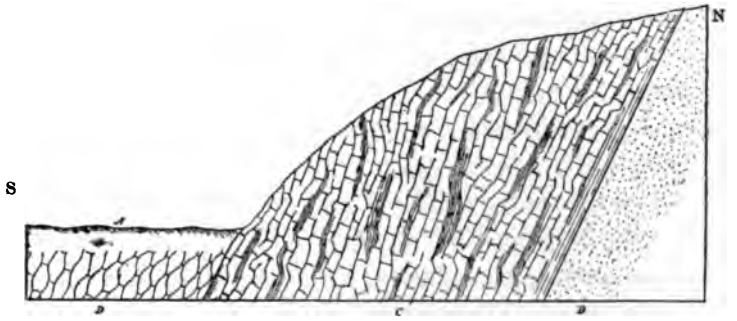

Figure 44. *Section at the Tenny Cape mine showing the position of the manganese-bearing rocks.*

A. Soil.

B. Sandstone.

C. Manganese-bearing limestone and shale.

D. Gypsum.

Horizontal scale: 1 inch—150 feet. Vertical scale: 1 inch—50 feet.

* This relation will be further discussed at the end of this chapter.

When the property was first opened, considerable quantities of ore were taken from the surface clay on the hillsides. The clay has resulted from the decay of the ore-bearing limestone and overlies its decomposed surface.

The following analysis by H. Poole shows the composition of a specimen of the ore from this mine:

*Analysis of manganese ore from Tenny Cape, Nova Scotia.**

Manganese peroxide	84.620
Ferric oxide	0.603
Soluble baryta	0.724
Insoluble (barytes ?)	1.728
Water of composition	3.630
Hygrometric water	1.660
	92.965

Manganese	53.47
Iron	0.42

The Parker mine.—The Parker mine is three quarters of a mile northwest of Tenny Cape and shows ore similar to that at the latter place and occurring under similar conditions. But little mining has been done and the property is at present (1890) idle.

The Moose Brook mine.—The Moose Brook mine is situated on Moose Brook, four miles northeast of Tenny Cape and half a mile south of the shore of Minas Basin. Small quantities of manganese have been mined on the property, but work has been suspended.

The Cheverie mine.—The Cheverie mine is situated near the village of Cheverie, on Minas Basin, just east of the mouth of the Avon estuary. The property consists of a rocky bluff rising from ten to thirty feet above the water and skirting the west shore of Cheverie Harbor for several hundred yards. It has been worked at several different times, but at present no mining is being done. Between

* The analysis was made by H. Poole and quoted by Professor H. How, in the London, Edinburgh and Dublin Phil. Mag., March, 1866.

two and three hundred tons of ore are said to have been shipped.

Most of the manganese at Cheverie is a black, crystalline ore composed partly of pyrolusite and partly of manganite. It occurs in a manner somewhat similar to that at Tenny Cape, but in smaller quantities. It is associated with white calcite in a network of small veins from an eighth of an inch to three or four inches in thickness, running through a calcareous breccia composed of broken fragments of massive and shaly limestone. The ore frequently encircles the fragments or runs along the bedding planes of the unbroken parts of the bed. In fact, it is found wherever a cavity or joint gives access to it, but it is usually in thin seams. Below the water it is said to be more plentiful and has been mined there on a small scale, but the operations were necessarily carried on at considerable expense and were soon abandoned. Frequently the calcite associated with the manganese is in the form of long crystals standing at right angles to the walls of the veins and forming a comb structure, in the center of which is the ore.

The sections in figure 45 illustrate the mode of occurrence of the ore. The one on the left shows a network of veins in the brecciated rock, while the other shows a more regular deposit occupying a plane of bedding in the shaly limestone, or calcareous shale, and representing a lenticular layer of ore.

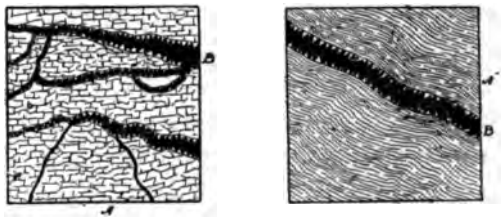

Figure 45. *Sections at the Cheverie mine, Nova Scotia, showing the mode of occurrence of the manganese ore.*

A. Manganese-bearing rock: in the first section the rock is a brecciated limestone, in the second a shaly limestone.

B. Manganese ore bordered by a "comb" of calcite crystals.

Scale: 1 inch=2 feet.

At the seaward end of the bluff in which this property is situated, the ore-bearing rock rests upon sandstone apparently similar to that at Tenny Cape, which is underlain in turn by a series of shales and sandstones. The rocks below the ore-bearing stratum dip at 5°–15° to the northeast, and none of them have the brecciated character of the latter rock. At the inland, or northern end of the exposure, the rocks appear to dip under the extensive beds of gypsum worked at Cheverie, though the contact of the rocks is obscured by soil.

The following analyses, the first by E. Gilpin, Jr., the second by H. How, show the composition of the pyrolusite and the manganite from this locality:

*Analysis of pyrolusite from Cheverie, Nova Scotia.**

Manganese peroxide	90.15
Ferric oxide	2.55
Lime	trace
Baryta	1.12
Moisture	2.05
Phosphoric acid	1.029
Insoluble matter	2.80
	99.699

Manganese	56.97
Iron	1.78
Phosphorus	0.45

Analysis of manganite from Cheverie, Nova Scotia.†

Manganese sesquioxide	86.81
Ferric oxide, barite, and loss	2.05
Water	10.00
Gangue	1.14
	100.00

Manganese	60.42

The Walton mine.—This property is at the village of Walton, on the shore of Minas Basin, twelve miles northeast

* E. Gilpin, Jr., Trans. Roy. Soc. Canada, March, 1884, p. 10.

† H. How, London, Edinburgh and Dublin Phil. Mag., March, 1886.

of Cheverie. It has been worked by Mr. Churchill of Walton, but at present (1890) it is idle.

The ore is mostly crystalline and contains both pyrolusite and manganite. It exists in the same associations as at Cheverie, except that here considerable quantities of barite, in the form of nests and nodules, occur in the manganese-bearing breccia. The ore-bearing rock lies on a sandstone which is underlain by interbedded shales and sandstones, similar to those at Cheverie.

Other localities in the Lower Carboniferous rocks on Minas Basin and in the adjacent country in Nova Scotia.—Besides the localities already described in Nova Scotia, several others have been found in the Lower Carboniferous marine limestone and some of them have been worked. Among these are: Onslow, Colchester county; Salmon River, near Truro, Colchester county; Noel, Douglas, and Rawdon, Hants county; near Glengarry, Pictou county; Springville, Pictou county; at Minudie and Amherst, Cumberland county; in Antigonishe county.

Localities in Nova Scotia in rocks other than Lower Carboniferous.—As already stated, the workable deposits of manganese in Nova Scotia, so far as known, are confined to the Lower Carboniferous rocks, but small quantities have been found in rocks of various other ages.

Mr. Gilpin,* in speaking of the existence of pyrolusite in the pre-Carboniferous rocks of Nova Scotia, says: "Between Halifax and Windsor, near Mount Uniacke, pyrolusite is found in small pockets and veins penetrating granite, and in quartzites of the auriferous Lower Cambrian of the Nova Scotia Atlantic coast. It occurs in veinlets in the granite of Musquodoboit, and as small irregular seams in the granite of Ship Harbour. In the hills south of Wolfville, in King's county, the same ore is found in quartzites and slates, presumably of Upper Silurian age."

Sir William Dawson mentions the existence of small quantities of manganese in the Coal Measures of the Pictou coal fields. †

* Trans. Roy. Soc. Canada, May, 1884, p. 8.

† Acadian Geology, second edition, 1878, p. 345.

Small and unimportant quantities of low grade manganese ore have been found in the Triassic sandstone in Nova Scotia. Sir William Dawson * mentions it as occurring at Cornwallis Bridge, and Mr. Gilpin notes† its existence at Cornwallis and at Wolfville. The latter authority also refers‡ to small quantities of manganiferous ochre having been mined in rocks of this age.

THE MANGANESE DEPOSITS OF NOVA SCOTIA.—*Cape Breton.*

General features.—Manganese has been found in Cape Breton, in the mountainous region lying between the Atlantic coast and Bras d'Or Lake. E. Gilpin, Jr.,§ in speaking of the geologic structure of this region, says: "In Cape Breton deposits of economic value occur only in the western part of the county of the same name. Here, at the head waters of the Salmon River, the lower members of the Carboniferous are met in a valley between the felsites of the Mira and East Bay hills. The space is generally occupied by the millstone grit, beneath the edges of which the marine limestones occasionally crop out, or the latter are excluded by the basal conglomerates. The following notes are from a visit to the Moseley (iron) mine, and from information kindly furnished by Mr. Fletcher, of the Canadian Geological Survey.

"The felsites of the Mira hills form a series of bays along which are exposed Carboniferous limestones, conglomerates, shales, and grits as they were accumulated subject to the varying conditions of the winds and currents of the period under consideration. At some points, the limestones rest on the felsites; at other localities, grits and shales intervene; elsewhere, the basal conglomerates are covered directly by the millstone grit. The manganese ores were discovered two years ago in one of these recesses where the felsites were succeeded by shales and grits, and finally by limestones, the latter apparently extending from point to point of the ancient bay."

Though the ores here, as elsewhere in Nova Scotia, are

* Acadian Geology, second edition, p. 113.

† Trans. Roy. Soc. Canada, May, 1884, p. 8.

‡ The Geological Relation of the Principal Nova Scotia Minerals, Trans. Amer. Inst. Mng. Eng., Vol. XVIII., 1889-90, p. 200.

§ Trans. Roy. Soc. Canada, May, 1884, p. 12.

found in rocks of Lower Carboniferous age, the mode of occurrence is sometimes different from that at the localities already described. The manganese is generally found in association with limestone and red shale, and these, though they show in their steep dips the result of the general disturbance which has affected the region, have not that minutely shattered and fractured character seen at the localities already described on Minas Basin. The only locality where any considerable work has been done in Cape Breton is at the Moseley mine.

The Moseley mine.—The Moseley mine is in Cape Breton county, near the head of Loch Lomond, and eight miles south of the village of Big Pond, on East Bay. It is the property of Mr. E. T. Mosely, of Sydney, and was opened in 1880. In 1881 seventy tons, and in 1882 fifty-nine tons of ore are said to have been shipped*, and similar quantities have been mined since then. The total production of the property up to 1890 is said to have been about 300 tons. The ore is packed in casks and most of it is sent to Boston.

The ore is found in both the crystalline and massive forms, part of it being pyrolusite. It occurs as nodules, pockets, and interbedded layers, in association with limestone and red shale, and sometimes, though rarely, it impregnates a coarse conglomerate. It is most abundant, however, in the red shale. Figure 46 shows the relation of the rocks on the property. The ore-bearing limestone, which is represented by bed A on the left side of the

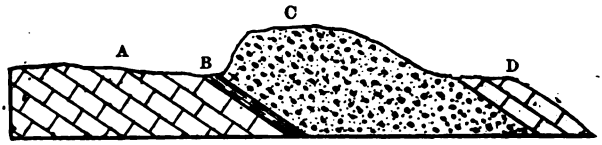

Figure 46. *Ideal section at the Moseley mine, Cape Breton, showing the position of the manganese-bearing rocks.*

A. Manganese-bearing limestone.
B. Manganese-bearing shale or clay.
C. Conglomerate.
D. Limestone containing, so far as known, no manganese.

* Hugh Fletcher, Geological Survey of Canada, 1882-3-4, pp. 92-93 H.

figure, is of a grayish-brown or purplish-brown color, of a crystalline structure, and contains thin interbedded films of red clay. It dips at an angle of about 30° and is directly overlain by the red clay or shale (bed B of the accompanying figure) which is an indurated brick-red clay, generally of a shaly or slaty texture and slightly calcareous. This varies from one foot to ten feet in thickness, and has been the source of most of the ore mined on the property. The ore in both the shale and the limestone is of irregular distribution: in some places layers of ore over a foot in thickness are said to have been found, while in others it is entirely absent.

Immediately overlying the red shale is a coarse conglomerate (bed C of the figure) composed of pebbles of metamorphic rocks, and often including pockets of red clay. Manganese has been found in the conglomerate, but only in very small quantities. It occurs either as a black stain coating individual pebbles and giving the bed a blotched appearance; or as thin layers from one to three inches in thickness; or in isolated pockets, filling the cavities between the pebbles. The ore is only seen in the conglomerate for short distances above the contact with the underlying bed. The conglomerate is overlain by a gray or grayish-brown crystalline limestone resembling the limestone that underlies the bed, except that it has not the purplish-brown color, and, so far as known, contains no manganese ore.

A large part of the ore taken from this property has been obtained in the soil, in loose masses which have weathered out of the red shale and the limestone, though several openings have also been made in the rock.

A short distance southeast of this locality, and still on land controlled by Mr. Moseley, is an indurated shaly clay, somewhat similar to that mentioned above, containing thin beds and lenticular layers of limestone from one to four inches in thickness, and associated with a deposit of siliceous pebbles cemented in a light green matrix. Manganese occurs

in the shaly clay and has been worked to a small extent. A large part of the ore obtained, however, has been found in loose nodules in the creek beds, having been washed out of the original rock. These "drift nodules" have a dull, earthy appearance on the outside, but inside they show the bright, black surface of the fresh ore.

THE MANGANIFEROUS IRON DEPOSITS OF NOVA SCOTIA.

Besides the manganese ores valued simply for their contents of that metal, or its peroxide, large quantities of manganiferous iron ore are found in Nova Scotia, especially in the counties of Pictou, Antigonishe, and Colchester. These ores usually occur in the form of brown hematites or of limonites containing variable amounts of oxide of manganese, either intimately mixed or as crystals encrusting cavities, or even in the form of wad. According to E. Gilpin, Jr., * the hematite at the Londonderry mine, Colchester county, sometimes contains as much as 14 per cent of peroxide of manganese. According to the same authority, the limonites in the neighborhood of Springville, Pictou county, occurring at the contact of the marine limestone of the Lower Carboniferous with the Silurian rocks, also often contain manganese; and in fact these ores frequently grade into true manganese ores, containing very little iron, as is shown in the accompanying analyses by Mr. Gilpin:

Analyses of manganese and manganiferous iron ores from near Springville, Nova Scotia. †

Manganese peroxide	.....	14.410
Manganese sesquioxide	62.950	.....
Ferric oxide	10.848	48.223
Alumina	2.880	0.015
Lime	7.280	0.015
Baryta	0.670	.....
Magnesia	1.630	.....
Carbonic acid	.....	.....
Sulphur	.....	0.480
Phosphorus	.....	0.020
Insoluble residue	2.731	25.130
Water of composition	.....	12.530
Moisture	1.450	
	90.439	100.808
Manganese	43.810	9.106
Iron	7.594	33.756

* Trans. Roy. Soc. Canada, 1884, pp. 7-8.

† Ibid., p. 12.

THE MANGANESE DEPOSITS OF CANADA OTHER THAN THOSE IN NEW BRUNSWICK AND NOVA SCOTIA.

The Magdalen Islands. — James Richardson, of the Geological Survey of Canada, reports * the existence of manganese ores in the Lower Carboniferous rocks of Amherst Island, in the Magdalen group, in the Gulf of St. Lawrence, but unlike the Nova Scotia ores of that age they do not appear to be associated with limestone. In speaking of this locality Mr. Richardson says: "Immediately under Demoiselle Hill, on Amherst Island, numerous blocks charged with peroxide of manganese, or pyrolusite, occur among the debris of the fallen cliffs. They are in pieces varying from one pound to ten or fifteen pounds in weight. There can be but little doubt that they are derived from a deposit, more or less regular, in the hillside, but which is completely concealed by the fallen debris. At a place bearing nearly due west from Cap aux Meules, at the distance of about a mile, and close to the English Mission church, similar pieces to those above described are very frequently picked up. Numerous stones of this character were observed by me at this locality, but as the ground was covered with growing crops I did not attempt any further search." These ores were found in a region of sandstone, shales, and gypsum beds, together with areas of dolorite and diasbase, but no limestones are reported in the neighborhood.

Newfoundland.—Dr. T. Sterry Hunt describes a deposit of massive carbonate of manganese at Placentia Bay, Newfoundland: † It is interbedded in slates which are supposed to be of Silurian age. It is described as "compact and impalpable in texture, brittle, with a conchoidal fracture and a feeble, waxy lustre; slightly translucent on the edges; color fawn to pale chestnut-brown; streak white; hardness 4.0; density 3.25. The specimen shows faint lines which seem to be those of deposition and give to the mass the aspect of a sinter. It is encrusted and penetrated in parts with black crystalline oxide of mangan-

* Geological Survey of Canada, 1879-80, p. 10 G.

† Ibid., 1857-58, pp. 204-5.

ese." The presence of oxide of manganese in this mineral is probably due to its partial decomposition.

An analysis of this mineral by Dr. Hunt gave carbonate of manganese 84.6 per cent, silica 14.40 per cent, a little iron and lime, and a trace of magnesia.

This deposit is of interest on account of the existence of the metal in the form of a bedded carbonate. It probably represents the former condition of many of the oxide ores of manganese elsewhere in the stratified rocks, but they have since been converted to their present more stable form.

"*Eastern townships.*"—Dr. T. Sterry Hunt* describes manganiferous dolomites in the metamorphic rocks of the "eastern townships" in the Province of Quebec. The dolomites of the 9th lot of the 9th range of the township of Sutton were found to contain manganese in the form of carbonate, sometimes to the extent of 7.65 per cent; and are often stained a brownish-black on the surface, as a result of its oxidation.

Bachewanung Bay.—At Bachewanung Bay, on Lake Superior, manganese has been found in "stringers" running through a reddish trappean rock, which strikes north and south and is about fifty feet in thickness.† It occurs with quartz, calcite, and fluorspar. "The ore, which is massive with small geodes of crystals, is described by Prof. Hadley as manganite, or hydrous sesquioxyd of manganese. * * * A specimen was found by assay to be equal to 60 per cent of peroxyd of manganese."

CHEMICAL ACTION IN THE MANGANESE DEPOSITS.‡

The chemical action which has taken place in the manganese deposits since they were laid down, has had a marked effect on their mode of occurrence. As in the case of most of the manganese deposits in America, the ores were probably laid down originally as carbonates or oxides, or both, during the deposi-

* Geological Survey of Canada, 1857-8, p. 204.

† Geology of Canada, 1863, p. 751.

‡ The subject of the origin of manganese deposits will be treated in the final chapter of this report. The present discussion relates only to the chemical changes that have taken place in the deposits since their deposition.

tion of the enclosing stratified rocks, and subsequently the carbonates were converted to the various oxides by the ordinary process of oxidation. This may have taken place either during the deposition of the enclosing strata, or subsequently to their elevation into a land area.

In many places the ores, whether in the form of nodules, pockets, or lenticular layers, still tend, in a general way, to preserve their bedded character and to follow the direction of the stratification, just as they were originally laid down. This is well seen at Markhamville, Quaco Head, the Glebe mine, Loch Lomond, and elsewhere. In these places the nature of the ore has probably been somewhat altered by chemical action subsequently to its deposition, but its position with relation to the enclosing strata is doubtless very much as it was when it was laid down.

In other places, however, the manganese bears a very different relation to the rock from what it did originally, and instances of this are seen at Tenny Cape, Cheverie, and elsewhere. At these places the enclosing rock has been brecciated and the ore, though it occupies a special horizon in the Lower Carboniferous series, has lost almost all traces of any stratified position that it might once have occupied in the rock, and occurs as nests and pockets, or as veins encircling and piercing the individual fragments. Sometimes, however, well defined flat nodules and lenticular layers of ore are found in planes of bedding, and are similar to those in places where the rocks have not been broken. The presence of these, as well as the fact that the rock, where it is not brecciated, is characterized by bedded ores, would seem to point to the probability that all the manganese in such localities once occupied positions conformable to the stratification of the enclosing limestone; and that the ore, as now found in the breccia, owes its position to chemical action, by which the manganese, as it originally existed, has been dissolved and re-deposited in the interstices, joints, and faults of the re-arranged rock. The manganese-bearing limestone is underlain by a series of sandstones, shales, and grits which are not marked by the brecciated condition of that rock.

The stimulating cause which brought on this chemical action in the ore deposit is somewhat obscure, but it seems possible that both it and the brecciation of the rock may be intimately connected phenomena; in fact, that the latter may have been the cause of the former, and that they may both be connected with the presence of gypsum. It will be observed in the detailed descriptions already given, that at Tenny Cape and Cheverie the brecciated ore-bearing limestone appears to dip under the gypsum; whereas at Markhamville, Quaco Head, and Loch Lomond, where gypsum does not overlie the ore-bearing limestones, the rock is not brecciated.

The gypsum represents an interbedded deposit in the associated strata, but the presence or absence of brecciation in the overlying rocks has not been investigated by the writer. Sir William Dawson, * however, describes a limestone overlying gypsum at Plaister Cove, Cape Breton, which has a peculiar broken appearance, showing masses of limestone cemented by gypsum. He states also that similar occurrences are not rare in connection with gypsum beds.

The gypsum itself, though not brecciated, is often much disturbed, showing a series of small abrupt undulations and folds.

The problem to be solved, therefore, in the manganese deposits is the brecciation of a certain series of strata, underlain by equally disturbed, but not brecciated beds, and overlain by large gypsum beds.† One of four causes usually operates in forming breccia deposits: (1) the surface breaking of the rock and the accumulation of its fragments at the base of cliffs or along the coast; (2) the crumpling of the bed by folding; (3) the shattering of the bed by igneous action; (4) chemical action, either in the bed itself or in the associated strata.

(1) The first cause is entirely out of the question, as the brecciated parts of the ore-bearing limestone blend into the solid

* Acadian Geology, third edition, 1878, p. 393.

† Sir William Dawson (Acadian Geology, third edition, p. 392) describes a gypsum bed at Plaister Cove which has a thickness of 150 feet. This, however, is exceptionally large. The thickness of the gypsum at the manganese localities was not accurately measured, but it would amount at least to a considerable fraction of the Plaister Cove deposit.

parts, and appear to occupy much the same position with relation to the associated strata as they originally did.

(2) The second cause of brecciation, that is by folding, does not seem probable, as the associated beds, though they are much disturbed and dip at steep angles, do not show the crumpling exhibited by the ore-bearing rock. The rock immediately underlying the ore-bearing horizon is a hard quartzite, and its greater resistance to crushing during folding might be said to explain the absence of brecciation in it. Below this, however, is a series of shales which would succumb to crushing just as easily as the ore-bearing rocks, or even more so; and yet, though these shales often occupy positions in which they have been subjected to just as severe a strain during folding as the ore-bearing rock, they are not marked, so far as seen, by the brecciation characteristic of the latter.

(3) The third cause of brecciation, that is by igneous action, is also improbable, since, had it acted, the brecciation would not be expected to be so continuous as it is along the strike of the rocks, and besides would not be confined to certain strata.

(4) Hence it becomes necessary to look to the fourth, or chemical cause of brecciation, and there appear to be reasons to suppose that chemical action in the gypsum beds has operated in bringing about the present brecciated condition in the manganese-bearing deposit.

The origin of gypsum in the large beds found in Nova Scotia is ascribed by Sir William Dawson* to the "conversion of submarine beds of calcareous matter into sulphate of lime, by free sulphuric acid, poured into the sea by springs or streams issuing from volcanic rocks." What are commonly called the gypsum beds really consist of gypsum and anhydrite, associated in varying quantities. Gypsum is a form of sulphate of lime containing 20.9 per cent of water, and anhydrite is a form containing no water. Anhydrite occurs in the gypsum as intimately mixed crystals, or as nodules, large masses, or even as solid layers, sometimes composing the larger part of the bed.

It is a well known fact that anhydrite, on exposure to per-

* Acadian Geology, third edition, 1878, p. 262.

colating waters, can absorb moisture and go into the hydrated form of sulphate of lime, or gypsum. Such a transition adds greatly to the bulk of the original anhydrite, increasing it, according to Geikie, * about 33 per cent; and where the anhydrite is confined on either side by the associated rocks, something must give way to afford space for this expansion. Such an expansion cannot be restrained, and the rocks will therefore be broken in the same way that a jug is broken when water is frozen in it. This action is a recognized agent in the local disturbance of rocks,† frequently producing dome-shaped hillocks or otherwise folding the strata. Elie de Beaumont ‡ describes cases in France where the strata have been upheaved and in some places overthrown by the expansion caused by the transition of anhydrite into gypsum.

If this same process of hydration has gone on in the region in question, and if the anhydrite now seen represents only the remains of a deposit which has been partly converted to the hydrous form, then the bed at present must have a much greater volume than it had before, and its expansion might readily have caused the brecciated character of the associated rocks. The amount of brecciation would depend on the amount of anhydrite that had been altered, and hence a possible explanation of the variable extent of the brecciation in different places. This expansion by hydration would not only explain the brecciation of the associated rocks, but also the numerous small undulating folds characteristic of the gypsum beds themselves.

The writer has not made any detailed examination of the gypsum of Nova Scotia, and cannot at present state the strength of the evidence as to whether or not the gypsum has been derived from anhydrite. This possible cause of brecciation, therefore, is offered only as a suggestion which a more thorough study of the region may either overthrow or substantiate.

Sir William Dawson, in a letter kindly written in answer to inquiries by the writer concerning the nature of the association

* Text Book of Geology, second edition, 1885, p. 319.

† Archibald Geikie, Text Book of Geology, second edition, 1885, p. 319. Joseph Prestwich, Geology: Chemical, Physical and Stratigraphical, Vol. I., p. 116.

‡ Explic. Carte Géol. de France, Vol. II., p. 89. (Prestwich).

of gypsum and anhydrite in Nova Scotia, has also mentioned this same cause of brecciation as possible, though he notes the difficulty of explaining exactly under what conditions an aqueous deposit of beds of anhydrite could have been originally laid down; unless, as he suggests, it was derived from the decomposition of calcium carbonate in situ, either by vapor or heated solutions of sulphuric acid.

The hydration of the anhydrite in the case in question, if such has taken place, has not been a sudden process, abruptly begun and quickly finished; it has probably been going on ever since the anhydrite itself began to be formed, and was partly accomplished before the beds were raised into a land area and tilted as they are now seen. In fact, it is natural to suppose that the anhydrite that is left is still undergoing a slow hydration, and is expanding in proportion to the amount of gypsum formed.

If the gypsum was derived, as suggested by Sir William Dawson, by the action of sulphuric acid on calcareous matter, and if it was originally formed in its hydrous condition, then another possible cause of the brecciation of the underlying beds might be found in the expansion due to the transition of the calcareous bed into gypsum.

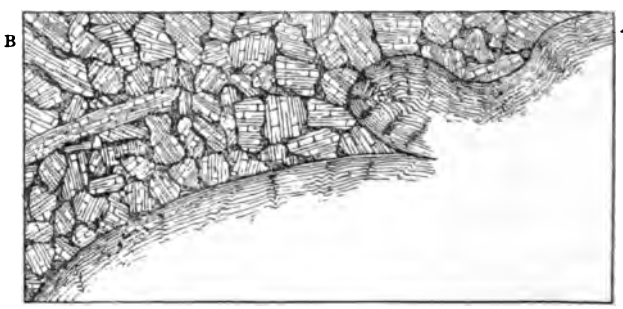

Figure 46. *Section at the Tenny Cape mine, Nova Scotia, showing the folding and brecciation in the manganese-bearing limestone and shale.*

A. Folded rock.

B. Brecciated rock.

Scale: 1 inch=6 feet.

Figure 46 illustrates the brecciation of the limestone and shaly material at the Tenny Cape mine. It will be seen by re-

ferring to figure 44, page 521, that the ore-bearing rock is bounded on the north by the underlying sandstone, or quartzite, and on the south by the gypsum bed. Figure 46 represents a view near the top of the hill in figure 44, and in the part of the ore-bearing stratum that abuts on the sandstone. The base of figure 46 belongs at the line of contact with the sandstone, and the right hand end of it is uppermost on the slope of the quartzite. It will be observed that a part of the bed is much broken, while the rest is greatly contorted. If the brecciation is due to a lateral thrust emanating from the gypsum, there is seen in this figure exactly the effect that would be expected from such a disturbance.

The resistant sandstone at the base of the ore-bearing stratum formed, probably both before and after it was tilted into its present position, an opposing barrier, against which the less resistant limestone and shale were jammed, and partly contorted into abrupt folds, and partly crushed and brecciated by the expansion from the gypsum on the south side of the bed.

In the crushing of the rock, fragments were formed, varying from particles the size of a grain of sand, or smaller, up to masses many feet in diameter. These were closely compacted, and, as the brecciation progressed, they were re-cemented by mineral matter, mostly calcite and sometimes manganese and other minerals; hence the numerous veins of crystalline calcite and manganese ore which frequently encircle individual fragments of rock, and the nests and pockets of these materials which fill every available crevice. Associated with the manganese and calcite are barite, selenite, and other minerals, which were probably deposited in the same way. The edges of the rock fragments are sometimes more or less rounded, a fact that is probably due to the dissolving action of percolating waters, and not to any process of rolling.

The solution and re-deposition of the manganese and other minerals in the breccia is probably due to several causes, which have combined to add to the solvent powers of percolating waters:

(1) The crushing of the rock by the transition of the anhy-

drite to gypsum would give rise to heat as a result of friction, and this, transmitted to percolating waters, would increase their powers to dissolve mineral matter. When they cooled their contents would be deposited in the crevices through which they were flowing.

(2) Another cause that may not only have operated in the solution and re-deposition of the ore, but may also have played a subordinate part in the brecciation of the limestone, is the fact that the reaction of sulphuric acid on limestone, in the formation of sulphate of lime, develops a large amount of heat, which would doubtless warm the waters in the underlying ore-bearing limestone to a greater or less extent, the degree of heat depending on the rapidity of the reaction. Such waters, before they were thus warmed, held in solution all the mineral matter they could take up in their present state, but the additional units of heat would increase their solvent powers, and tend to disintegrate the limestone and re-arrange the ore. Moreover, in the reaction of sulphuric acid on limestone, a large quantity of free carbonic acid is evolved, and its amount is in direct ratio to the amount of gypsum formed. A large part of this acid would doubtless be carried off in the sea water, but some of it would find its way to the underlying ore bed, thus still farther increasing the solvent powers of the waters.

It also seems probable that the remarkable purity of the ore in many places in the shattered rock may be due to the chemical action that has gone on. The process of dissolving it would free it from the earthy impurities that were originally deposited with it, and when it was re-deposited in the breccia, it would be associated only with such materials as were taken in solution with it and crystallized out in the same places. In support of this view it may be said that the purest and most highly crystalline ore is found in the irregular veins already referred to, while the ore in the bedding planes, in places where brecciation has not taken place, is often, though not necessarily, earthy and less crystalline, or even massive.

CHAPTER XXI.

THE ORIGIN AND CHEMICAL RELATIONS OF MANGANESE DEPOSITS.

GENERAL STATEMENT.

The nature and mode of occurrence of manganese deposits, and some of the chemical changes that have taken place in them have been described in previous chapters. It is the object of the present chapter to explain the original source of the manganese as now found in the Paleozoic and later rocks, and the various stages that the ore has passed through in acquiring its present chemical and physical condition.

It will be attempted to show that the different steps in the formation of manganese deposits have been as follows:

(1) The derivation of the manganese from the decay of the Archean and other pre-Paleozoic rocks, and from the products of igneous action.

(2) The solution and transportation of the manganese in the form of soluble organic and inorganic salts of the metal.

(3) The precipitation of the manganese as oxide or carbonate.

(4) The conversion of the carbonate into oxide.

(5) The subsequent decay of the rocks which were deposited with the ore, and an accompanying change in the nature of the ore and sometimes in its physical condition.

It will be observed that these stages in the history of the deposits involve a primary decay of rocks as a source of the ore, an intermediate series of chemical reactions, and then a secondary decay of the newly formed deposits. All these transitions can be seen going on even at the present time, and, as will be shown later in this chapter, many deposits can, by a careful

study of the region in which they are found, be traced from their original source to their present resting place.*

The various stages in the formation of manganese deposits are similar, in many respects, to those known usually to have gone on in the formation of iron ores, but they differ in many minor details: both metals have their origin in the pre-Paleozoic rocks, and in many places they form parts of the same minerals in those rocks; they go into solution in the same manner, and are transported in the same surface waters; but in their modes of deposition, though they sometimes resemble each other, they often differ considerably, and different chemical changes go on in the subsequent alteration of the oxides. Hence, though manganese is often associated with iron ore deposits, it is sometimes comparatively free from such accompaniments; and even when mixed with iron ores, the association takes place in variable proportions and in many different ways. The deposits of both are so closely related in their origin, that it is necessary, for the proper understanding of the origin of manganese deposits, to refer more or less to that of iron deposits, though the latter will be discussed only to the extent of its connection with manganese.

The subject will be treated under the following general heads:

Summary of the nature and occurrence of manganese ores.
The sources of manganese.
The forms of manganese deposited at ordinary temperatures.
Conditions of deposition of manganese.—*General statement.*
Conditions of deposition of manganese.—*In springs and rivers*
Conditions of deposition of manganese.—*In local basins.*
Conditions of deposition of manganese.—*On the sea floor.*
The association and separation of manganese and iron.
Secondary chemical and physical changes in manganese deposits.
The origin of the manganese deposits of the Batesville region of Arkansas.

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* These statements do not refer to the manganese minerals found in the silver deposits of the Rocky Mountains and elsewhere, which are often of vein origin, formed in a very different manner from the ordinary bedded deposits to which the present discussion is confined.

SUMMARY OF THE NATURE AND OCCURRENCE OF MANGANESE ORES.

The nature and modes of occurrence of manganese ores have been described in previous chapters, but a brief summary of the principal features of the deposits as they now exist may be of assistance in the following explanation of their former condition.

Manganese occurs in nature in four stages of oxidation: the protoxide, MnO; the proto-sesquioxide, Mn_3O_4 (or MnO, Mn_2O_3); the sesquioxide, Mn_2O_3; and the peroxide, MnO_2*. These four oxides are found in nature as distinct minerals. The protoxide, sesquioxide, and peroxide occur in both the anhydrous and hydrous forms, while the proto-sesquioxide occurs, so far as known, only in the anhydrous form. The following table shows the mineralogical representatives of the different oxides and their relations to each other.

Forms of manganese oxides in nature.

Chemical composition.	Anhydrous form.	Hydrous form.
Protoxide (MnO)	Manganosite (MnO)	Pyrochroite (MnO,H_2O)
Proto-sesquioxide (Mn_3O_4)	Hausmannite (Mn_3O_4)	
Sesquioxide (Mn_2O_3)	Braunite† (Mn_2O_3)	Manganite (Mn_2O_3,H_2O)
Peroxide (MnO_2)	Pyrolusite, polianite (MnO_2)	Psilomelane‡ Wad‖

* Besides these forms manganese can be obtained artificially, as manganates and permanganates, in two more highly oxidized conditions than any of those just mentioned.

† Some forms of braunite contain from 7 to over 8 per cent of silica. (See pages 80 and 148–154.)

‡ Various formulas have been given for psilomelane, but it is usually considered to be essentially a peroxide of manganese with variable amounts of water, potash, and baryta, and sometimes a certain amount of protoxide of manganese (MnO) and sesquioxide of manganese (Mn_2O_3).

‖ Wad is essentially a hydrous peroxide of manganese with other ingredients in very variable quantities. Certain of these ingredients are supposed by some to be in chemical combination in the material, while by others they are supposed to be mostly mechanical admixtures.

By the combination of oxides of manganese with the various mineral forming acids, the manganese-bearing minerals, such as carbonates, silicates, phosphates, tungstates, and others are formed.

The workable deposits of manganese in America, so far as yet discovered, are in the form of oxides, generally the peroxide and the sesquioxide. The silicates occur in large quantities in the crystalline rocks, but, on account of their high percentage of silica, are not at present available as a source of manganese. The carbonate is of common occurrence, but in small quantities.

Manganese deposits * occur in rocks of various kinds, limestones, shales, sandstones, or slates, mentioned in the order of their importance to the subject in question. The ores usually tend to follow planes of bedding, occurring either as lenticular layers, pockets, or nodules, though the intermittent character of the deposits sometimes obscures this tendency. Whatever their condition, however, they follow certain stratigraphic positions in the formations containing them, and even if they are only in the shape of nodules, these can often be seen studding the surface of certain planes of bedding. In some places pockets and irregular "stringers" of ore cut directly across the stratification, but they rapidly thin out in these transverse directions and are due to a secondary chemical change, which has dissolved and re-deposited the ore, as already explained in the case of the Appalachian Mountains, Nova Scotia, New Brunswick, and elsewhere.

The ores as found on the surface are often, or even generally in a residual clay which represents the product of the decomposition, in situ, of the original ore-bearing rock. This clay sometimes extends downward for a depth of over two hundred feet, but eventually blends into the undecomposed bed. Sometimes, however, the manganese-bearing stratum has not decayed even on the surface, and the ore is found in the original rock.

The ore most commonly associated with manganese is iron: there is almost always some of this ingredient in all manganese

* The deposits here referred to are those which are of primary importance as a source of manganese, and not the manganiferous silver ores, which occur in associations entirely different from those of the deposits in question.

deposits, though it is often in insignificant quantities and manganese is the predominating ore; while elsewhere manganese occurs as a subordinate constituent of iron ore deposits. Besides iron the most common mineral accompaniments of manganese deposits are calcite and barite; while in intimate association with the composition of the ores themselves are nickle, cobalt, zinc, lead, silver, phosphorus, and numerous rarer elements, as explained in chapter V.

THE SOURCES OF MANGANESE.

General statement.—The sources of manganese in the Paleozoic and later sedimentary rocks are to be found in the pre-Paleozoic * and in the igneous rocks.

The fact that the largest manganese deposits in the United States and Canada are in the neighborhood of such rocks is in itself suggestive; but when it is found that large areas of bog manganese ore occupy basins in the decayed surface of the pre-Paleozoic rocks, and that the river pebbles in areas of these rocks are frequently encrusted with a black coating of oxide of manganese, other facts are encountered which at once suggest a possible pre-Paleozoic source for manganese deposits. When, moreover, it is observed that volcanic breccias are sometimes cemented by manganese, that segregated masses of oxide of manganese are sometimes found in lava, and that the manganese nodules dredged up from the sea bottoms are in intimate association with volcanic debris, the possible source of manganese in igneous rocks claims attention. When these two classes of rocks, pre-Paleozoic and igneous, especially the former, are examined in their more minute details, and it is found that of the minerals composing them, those containing manganese are among the most common, the probability of their being the source of manganese in the younger rocks becomes established.

The comparative importance of pre-Paleozoic and igneous rocks as sources of manganese is often somewhat uncertain, as

* By the pre-Paleozoic rocks are here meant the Archean rocks and those other rocks older than Paleozoic which have been differentiated by various authorities from Archean.

in many cases they are so intimately associated that it is difficult to tell, without an exhaustive series of analyses, which have afforded the larger quantity of the manganese in any one place; but inasmuch as a large number of the pre-Paleozoic rocks may themselves have had either a direct or an indirect igneous origin, the exact determination of this question loses its importance. So far as the facts at hand show, however, the various pre-Paleozoic rocks, especially the Archean, whatever their origin, appear to have played a far more important part as a source of manganese than the later igneous rocks. In the following discussion both classes of rocks will, for the sake of convenience, be treated under the heading of crystalline rocks, though, unless otherwise stated, the remarks will refer more especially to the pre-Paleozoic rocks.

Distribution of crystalline rocks.—The crystalline rocks form a broken fringe around the Mississippi basin, extending on the east from Maine to Georgia; on the north from Maine up the valley of the St. Lawrence, through the region of the Great Lakes, and thence to the northwest; on the west extending along the line of the Rocky Mountains; on the south occurring in local areas in central Texas and southeastern Missouri. These exposures once represented more or less isolated areas in the Paleozoic sea, and deposits of manganese ore were formed at many places within the area enclosed by them, especially along their borders.

In the Appalachian region the manganese deposits in the early Paleozoic rocks form an intermittent belt along the northwestern side of the barrier of crystalline rocks, from northern Vermont, down the eastern side of the valley of Lake Champlain, through Virginia, Tennessee, Georgia, and into Alabama.

In New Brunswick and Nova Scotia manganese deposits in Lower Carboniferous limestone lie along the border of the pre-Paleozoic and igneous rocks of the northern Appalachians.

In northern Arkansas the manganese ores in Silurian limestone, in the Batesville region, lie to the south of the Archean area of Missouri.

In Colorado manganese and iron ores in the Paleozoic

rocks border the area of crystalline rocks of the Rocky Mountains.

Manganese minerals in the crystalline rocks.—The source of manganese in the crystalline rocks exists mostly in the various silicates containing manganese as their base, or as one of their bases. By the chemical decomposition of the silicates, the manganese is abstracted, taken into solution, and carried off by springs or surface waters to be deposited among the sediments forming elsewhere.

Among the most common silicates are those containing manganese and iron, either separately, in different minerals, or together in the same mineral. The numerous manganiferous silicates have already been referred to in chapter V. and do not require further discussion here. Among the best known of them are: rhodonite; the manganiferous forms of pyroxene, amphibole, and garnet; the manganiferous minerals of the olivine group, such as tephroite, roepperite, knebelite, danalite, and helvite; the manganiferous mica, manganophyllite; the manganiferous epidote known as piedmontite; the minerals ilvaite, ardennite, trimerite, and numerous others.

Besides existing in the form of silicates, manganese often occurs in the crystalline rocks as carbonate, (rhodochrosite or diallogite). This is frequently associated with rhodonite, and has in some cases probably resulted from the alteration of that mineral. The rarer manganese minerals, such as phosphates and tungstates of manganese and other forms, also occur in the crystalline rocks, but they are in exceedingly small quantities compared with the silicates.

Though the oxides of iron in the forms of magnetite and hematite are frequently found in large quantities in the crystalline rocks, the free oxides of manganese are proportionally much rarer in such rocks, except where they occur as a secondary product resulting from the superficial oxidation of the silicates and other manganese-bearing minerals.* Sometimes, however, oxides of manganese do occur in the crystalline rocks, either in

* The surface outcrops of silicates of manganese are almost always more or less extensively converted to oxides.

a free state or with magnetites and hematites, and also in other associations, such as in the mineral franklinite, an oxide of iron, zinc, and manganese.

It will thus be seen that though the variety of manganese-bearing minerals in the crystalline rocks is large, the silicates are by far the most plentiful, and it is to them that it is necessary to look for the principal source of manganese in later clastic rocks. When the silicate is in the form of rhodonite, it occurs as interbedded layers, lenticular pockets, and possibly veins in granitic, gneissic, and schistose rocks. When it is in the form of garnet, it occurs either in separate crystals, scattered in greater or less quantities through certain rocks, or, as in the case of the spessartite and other manganese-bearing garnets described in the central Texas region (chapter XVI.), it exists in the form of apparently interbedded layers.

Manganiferous augite and hornblende, as well as the other rarer manganese-bearing silicates, usually occur in nests and pockets. Many of the silicates also often occur as minor constituents of veins in the crystalline rocks.

Agents of decay of the crystalline rocks.—The surface outcrops of the crystalline rocks have all been decomposed to a greater or less degree by the combined action of carbonic acid and other organic and inorganic acids, and of oxygen, surface waters, and sometimes other agencies. It was formerly supposed that carbonic acid was the principal organic agent in the decay of rocks, but Julien* has shown that other acids formed by the decay of organic matter, such as humic, crenic, apocrenic, formic, acetic acids, etc., may have played an important part, often considerably more so than carbonic acid. Locally, however, in special cases where it is set free in large quantities by the action of acidulated waters on limestone, carbonic acid may have a far more powerful effect than the other organic acids.

Sulphuric acid formed by the decomposition of iron pyrites in the crystalline rocks, has in some cases been an active agent in hastening decay. This acid, as well as hydrochloric and other

* Alexis A. Julien, Proceed. Amer. Assoc. Adv. Sci., Vol. XXVIII., 1879, pp. 311-410.

acids, might originate also in the vapors produced by igneous action. It has been suggested that nitric and nitrous acids, generated in thunder storms, have played a subordinate part as decomposing agents when taken up in surface waters and carried down into the rocks.

Climate also has an influence on the rapidity of the decomposition of rocks, as in a dry equitable climate they will succumb much less rapidly than where they are exposed to the action of repeated rainfalls and of sudden changes of temperature, causing expansions and contractions which assist in a rapid breaking up of the rocks.

Mode of decay of the crystalline rocks.—The decay of crystalline rocks is not simply a process of mechanical disintegration, but it also represents profound chemical changes in the mineral constituents of the rock, which give rise to mineralogical combinations totally different from the original forms. The constituents of most crystalline rocks might be divided, in relation to their action during decay, into stable and unstable minerals. The stable class is represented by quartz, which, during the decay, undergoes little or no chemical change, but is simply broken up mechanically, carried off as sand, and deposited in the beds of sandstone common in all geologic ages from Cambrian to recent.

In the unstable class are grouped the large variety of silicates, which compose the mass of all granites, gneisses, schists, and other crystalline rocks. When silicates decompose under surface influences, the metallic bases combine with carbonic and other organic or inorganic acids, and are removed in solution as bicarbonates or salts of the other acids. A part of the silica is also taken up in solution, and the rest, together with the alumina, remains as a residual clayey product, which mixes with the sand derived from the quartz of the original rock. When this residual material is finally eroded by surface waters, the whole mass is sorted by the action of running water, the sand being deposited first, and the lighter material being carried on to form the sediments of future beds of shale and slate.

The iron and manganese are carried off in solution and are

eventually precipitated with the sandy and clayey sediments then forming in the bottom of the sea, coastal lagoons, or bogs into which the surface waters drain. The carbonates or other salts of lime, magnesia, soda, potash, etc., derived from the silicates, are also carried off in solution and go to form their part of the mineral constituents of almost all natural waters.*

Depth of decay of the crystalline rocks.—In the United States the decay of rocks is especially noticeable in the south, where the outcrops exist as soft clay beds, or as an angular gravelly material composed of fragments of the original rock which have so far escaped decomposition. In the northern states the soft decomposed rock which had gradually collected through geologic ages, has been mostly removed by glacial action in late geologic times, and as the interval that has elapsed since then has been too brief to allow of any great decomposition, the smooth, hard, glaciated surfaces of the crystalline rocks characteristic of New England and Canada are exposed. In some places, however, where the products of decay have been protected by the local topographic features of the country, they still retain a considerable thickness.

C. U. Shepard,† as early as 1837, described the formation of extensive deposits of clay from the decay of the feldspathic rocks of western Connecticut.

At the western base of Hoosac Mountain, Massachusetts, where the decayed rock has escaped the erosion of glacial action, the steeply dipping gneisses and schists have, according to T. Sterry Hunt, completely decayed to a depth of over 200 feet; while at 230 feet the decay has not been so general, though evidences of it are seen to over 300 feet.‡

According to Dr. Hunt || the veins of cupriferous pyrites in the crystalline rocks of Ashe county, North Carolina, have been decomposed to a depth of from 40 to 70 feet.

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* Various other chemical changes also take place in the decay of the crystalline rocks, such as the formation of kaolin, hyalite, and numerous other minerals, but these have no connection with the present subject.

† Geol. Survey of Connecticut, 1837, pp. 73-75 (quoted by T. S. Hunt).

‡ T. Sterry Hunt, Mineral Physiology and Physiography, 1886, pp. 256-257.

|| Ibid., pp. 258-259.

Raphael Pumpelly* describes the extensive decay of the Archean rocks of southeastern Missouri, and the formation, as at Iron Mountain, of residual clay containing iron ore which once existed in the original rock. W. B. Potter† has lately fully described and illustrated the occurrence of these iron ore deposits and has also explained the relations of certain of them to underlying Archean and overlying Paleozoic rocks.

In the central Texas region the feldspathic rocks have often been disintegrated and more or less decomposed to considerable depths, and in the bluffs of some parts of the Colorado River, in Llano county, ledges of angular feldspathic gravel mark the outcrop of these rocks.

In the silver deposits of Butte City, Montana, the sulphides of iron, lead, zinc, etc., and the carbonate and silicate of manganese have all been more or less completely converted to oxides down to the water level of the country,‡ which is sometimes 200 feet‖ below the surface, while below that point they assume their original unaltered condition.

In Brazil the crystalline rocks in some places have been decomposed to a depth of 800 feet or more.§

According to Raphael Pumpelly, many inclosed basins in crystalline rocks in Asia have been formed by the unequal decay of the rock and the removal of the residual materials by winds.¶

The decay of the crystalline rocks is not confined to later geologic times, but dates back, as discussed by T. Sterry Hunt,** to the earliest ages to which there are means of tracing it.

Thus it will be seen that by the decay of the crystalline rocks continued through geologic ages, a large amount of manganese has been continually supplied in solution to the circulating waters, and when the conditions suitable for its precipitation

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* Geological Survey of Missouri, Iron Ores and Coal Fields, 1872.

† Trans. Amer. Inst. Mng. Eng., Vol. XIX., 1890-91.

‡ W. P. Blake, Trans. Amer. Inst. Mng. Esg., Vol. XVI., 1878-79, pp. 74-75. E. D. Peters, Jr., Mineral Resources of the United States, 1883-1884, p. 380. See also this report, p. 453.

‖ W. P. Blake, Ibid., p. 74.

§ Liais, Géologie du Brésil, p. 2. (Cited by Geikie).

¶ Amer. Jour. Sci., 3rd series, Vol. XVII., 1879, pp. 139-140.

** Mineral Physiology and Physiography, pp. 269-270.

have been realized, it has been again laid down in the form of ore deposits.

FORMS OF MANGANESE DEPOSITED AT ORDINARY TEMPERATURES.

General statement.—The mineralogical forms in which manganese is deposited from solution at ordinary temperatures, depend on the conditions of the air and water, whether of an oxidizing or reducing nature, and on the character of the associated inorganic or organic matter, either in solution with the manganese or as a sediment on the floor of the sea, lagoon, or bog in which deposition takes place. Manganese is laid down mostly as oxide and carbonate, and possibly sometimes, though very rarely, as sulphide; while iron at ordinary temperatures is laid down as oxide, carbonate, sulphide, or as the hydrous silicate of iron and potash known as glauconite. In the cases of both manganese and iron one of the most common forms of deposition is as carbonate, which is subsequently often converted to oxide.*

The metamorphism at high heat of the forms of manganese laid down at ordinary temperatures, in connection with other materials, gives rise to various silicates and other manganese-bearing minerals, as described later in this chapter.

Deposition as oxide.—When the solutions of organic or inorganic salts of iron and manganese are freely exposed to the action of air, as in shallow or rapidly running water, free from contact with organic matter, they are quickly oxidized, and the iron is precipitated in the form of hydrous sesquioxide, while manganese is precipitated either as a simple carbonate or as peroxide (probably sometimes also as sesquioxide) in a higher or lower state of hydration. Manganese seems often to retain its carbonate form during deposition with more tenacity than iron.

The precipitation of the oxides is seen going on in many surface waters at the present time: the slimy, rusty scum ooz-

* When the manganese and iron were originally in solution as other organic salts than carbonates, it is possible, as suggested by Julien (Proceed. Amer. Assoc. Adv. Sci., Vol. XXVIII, 1879, p. 356) for calcareous concretions containing iron and manganese, that the carbonates now [redacted] and "may be merely the fixed residue of organic acids of more complex form, * * * "

ing out of the sides of ditches made in low places, the iridescent brown crust often mistaken for oil on spring water, and the brown incrustation on many river pebbles, represent hydrous peroxide of iron precipitated from the solution of bicarbonate or other salts of iron.

Similar occurrences take place with manganese, but, as that metal is rarer, its presence is less often observed and it is usually mistaken for iron. Thus the waters of many springs deposit a black sediment of oxide of manganese near the point where they come to the surface of the ground. This is especially true of hot springs where the waters, when they cool on the surface and become partly oxidized, rapidly deposit part of the excess of mineral matters which their high temperature and freedom from oxidizing influences underground had enabled them to carry up. Some of the Steamboat Springs in western Nevada deposit oxide of manganese among their other metalliferous sediments; and the warm springs of Golconda, Nevada, form a calcareous and siliceous sinter often highly stained with manganese. The Hot Springs of Arkansas deposit a calcareous sinter which is impregnated with oxide of manganese in the same manner.

A hot spring near the Cape of Good Hope,* having a temperature of 110° Fahrenheit, deposits oxide of manganese in its discharge channel; a mineral spring in the house of the Russian Crown at Carlsbad,† with a temperature of 68° Fahrenheit, also forms manganiferous deposits; and the springs of Luxeuil ‡ as well as the water in a certain mine at Freyberg form manganiferous sediments. ‖ The portion of manganese which is not precipitated at or near the mouths of the springs, is carried on to the streams into which the springs drain, and there partly deposited on the river gravel or the finer sediments, and partly carried still farther, until it eventually reaches the sea or any other basin to which the waters of the region are tributary. Thus a black incrustation of manganese is often seen on the

* Townsend, l'Institut., 1844, No. 529. (Bischof).

† Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX, p. 754. (Bischof).

‡ Braconnot, Ann. de Chim. et de Phys., Vol. 18, p. 221. (Bischof.)

‖ Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

pebbles in ravines and in river beds, especially at waterfalls, where the rapid movement of the water has allowed the free oxidation of its metalliferous contents. This is especially noteworthy in some of the canyons in the crystalline rocks of Colorado: in Virginia Canyon, near Idaho Springs, about forty miles west of Denver, a black cement of manganese oxide binds together the detrital material that has accumulated in the bottom. On either side of the canyon the gneissic and schistose rocks form steep bluffs, in which rhodonite is said to be found in the silver veins of the region, thus revealing a probable source of the oxide. Such occurrences are local, however, and the manganese cements the material only in spots. At the junction of Virginia Canyon and Boomerang Gulch, a deposit of rock fragments thus bound together varies from 6 to 10 feet in thickness. A manganese coating covers the pebbles in many of the rapid streams in the Archean area of New England, and David A. Wells* describes it on the Merrimac and elsewhere. Dr. J. C. Branner, during his geologic investigations in Brazil, observed a similar coating of manganese oxide in the rapids of the Rio Sao Francisco at Piranhas, below the falls of Paulo Affonso; in the rapids at the head of navigation on the Rio Araguary; and near the head waters of the Paraguay. The manganese oxide which sometimes coats pebbles in Lower Carboniferous conglomerates in New Brunswick and Nova Scotia may have been derived in a somewhat similar manner by the splashing of water on the shore.

John Davy † describes a coating of manganese oxide on the river pebbles in the lake district of Westmorland and Cumberland, England.

Thus it will be seen that when waters containing manganiferous solutions are in rapid motion, as at the mouths of springs or in rivers or creeks, they are freely exposed to oxidation, and consequently the part of the manganese that is precipitated is usually in the oxide form.‡ The part that is not

* Amer. Jour. Sci., 2d series, Vol. XIII., 1852, pp. 9-11. Mr. Wells believes the manganese to have been derived, by the dissolving action of organic acids, mostly from a double carbonate of lime and manganese in igneous and metamorphic rocks.

† Edinburgh New Phil. Jour., July, 1851, pp. 87-88.

‡ A case of deposition of manganese as carbonate at the mouth of a spring will be described later in this chapter.

precipitated, however, is carried on to the body of water to which the streams are tributary and there precipitated, sometimes as oxide and sometimes as carbonate.

Deposition as carbonate.—When the manganiferous solutions in the form of surface waters are protected from oxidation by being in the presence of a reducing agent, such as vegetable or animal matter, they are often precipitated as carbonate. The bicarbonate or other salts of manganese that are in solution, however, are so easily oxidized that unless the protection from oxidation is very complete, the manganese is precipitated as oxide. Hence the vegetation of bogs is sometimes coated with oxide of manganese. This occurrence is more commonly seen with iron than with manganese, on account of the greater abundance of the former material, and a rusty scum on the vegetation is characteristic of the bogs or marshes into which waters laden with solutions of iron empty.

Fresenius * has shown that the warm waters of Wiesbaden, which, among other constituents, contain manganese and iron, deposit the iron in the form of oxide, while the manganese is carried on farther in solution and deposited as carbonate. This would point to a greater stability in nature for carbonate of manganese than carbonate of iron, † though under many circumstances they are both easily oxidized.

Under suitable conditions, however, the carbonate of both metals may be deposited, often in the same spot. Hence in the Coal Measures, where carbonaceous matter is abundant not only in the coal beds, but also in lesser quantities throughout the associated rocks, the characteristic deposits of more or less manganiferous siderite, or carbonate iron ore, occur. These ores contain from a fraction of a per cent to over four per cent of carbonate of manganese. ‡ H. D. Rogers || suggested in 1858 that the siderite deposits were caused by the conversion of sesquioxide of iron into carbonate by

* Jahrb. des Vereins f. Naturkunde in Herz. Nassau, Vol. VI., p. 160 (Bischof).

† It is a well established fact in chemistry that the carbonate of manganese is a more stable material than carbonate of iron.

‡ See H. D. Rogers, Geol. Survey of Penn., Vol. II., 1858, p. 739; also Andrew S. McCreath, Second Geol. Survey of Penn., Vol. M. M., 1879, pp. 162-166.

‖ Geological Survey of Pennsylvania, Vol. II., 1858, p. 738.

organic matter and its subsequent segregation as now found in layers and nodules.

Similar associations of the two carbonates are seen in various other places and in both the same and different geologic associations: thus T. S. Hunt * describes carbonate of iron containing greater or less quantities of manganese, and sometimes blending into pure carbonate of manganese (rhodochrosite), on the east side of the Hudson River in New York and Massachusetts. Hunt also describes the existence of comparatively pure carbonate of manganese in slates, probably of Silurian age, at Placentia Bay, Newfoundland. † Spiegeleisen is made in Germany from a spathic iron ore from Nassau ‡ containing sometimes over eighteen per cent of carbonate of manganese, and Bischof || describes other spathic iron ores in Germany containing from three to forty per cent of the same material, as well as pure carbonate of manganese from Nagyag, Transylvania.

During the precipitation of the carbonates, a certain amount of organic matter is carried down with them, and hence the analyses of these ores often show a considerable amount of such impurities. This is especially noticeable in the Carboniferous rocks, and Bischof § describes carbonate of manganese from Nagyag, in Transylvania, which contains from 6.22 to 10.11 per cent of organic matter.¶

Deposition as sulphide. — Iron is often deposited in the form of sulphide (iron pyrites), but manganese is rarely found in that form, and when it does occur it is always in very small quantities. Iron forms three sulphides in nature, pyrite, pyrrho-

* Mineral Physiology and Physiography, p. 261.

† Geological Survey of Canada, 1857-1858, p. 204-205; also Amer. Jour. Sci., Vol. XXVIII., 1859, p. 374.

‡ D. Forbes, Journal Iron and Steel Inst. 1872, I., p. 168.

|| Elements of Chem. and Phys. Geology, Vol. III., pp. 496-507.

§ Ibid., p. 507.

¶ It has been suggested by Julien (Proc. Amer. Assoc. Adv. Sci.. Vol. XXVII., 1879, p. 230) that the organic matter found in many iron and manganese oxides may be the remains of the organic acids that were combined with the metals.

tite, and troilite,* but pyrite is the most common and occurs in all rocks from Archean to recent. It is formed in nature by the action of soluble sulphides or sulphuretted hydrogen on soluble salts of iron, or by the reduction of the sulphate by organic matter.

Manganese forms two sulphides in nature, a monosulphide known as alabandite, and a disulphide known as hauerite. † Both minerals are very rare and are so unstable that they rapidly become oxidized on exposure. Alabandite is the less rare form and usually occurs as a subordinate constituent of metalliferous veins. It is said to be found at the Caledonia silver mine, Kingston, New Mexico, and in the silver deposits of Potosi, old Mexico. It also occurs, according to J. D. Dana,‡ in association with tellurium, quartz, and carbonate of manganese in the gold mines of Nagyag, Kapnik, and Offenbanya, in Transylvania; at Gersdorf near Freiberg; and at Morococha, Peru. Hauerite occurs with gypsum and sulphur at Kalinka, Hungary.

Though the sulphides of manganese are easily oxidized, they are not so unstable that, had they ever been formed in considerable quantities in sedimentary deposits, they would, even at considerable depths, have left no trace of their former presence. Moreover the sulphide of manganese, as produced artificially, || is soluble in certain organic acids, noticeably acetic, and as the conditions for the deposition of sulphides of metals in sedimentary deposits generally require the presence of organic matter, it is not improbable that some of the acids given off by such matter might be such as would dissolve the sulphide of manganese. Thus there is a possible reason why manganese would not be deposited as sulphide under certain conditions.

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*Troilite has been found only in iron meteorites. (E. S. Dana, Text Book of Mineralogy, p. 242)

†Manganese also occurs in youngite (Hannay, Min. Mag. I., 152, 1877) which is a sulphide containing lead, zinc, iron, and manganese; but the composition of this material is doubtful, and it is considered by J. D. Dana (System of Mineralogy, fifth edition, Appendix III., p. 133) to be a mechanical mixture.

‡System of Mineralogy, fifth edition, 1883, p. 47; and Appendix III., p. 3.

||When manganese is precipitated artificially as sulphide it is usually in the form of the monosulphide, in either a hydrous or an anhydrous form.

which would cause the precipitation of sulphides of iron and other metals. Hence it seems probable that the sulphide has rarely, if ever, been the original form of any considerable deposits of manganese ore laid down under the usual conditions of sedimentation.

The artificial formation of sulphide of manganese (alabandite) in the laboratory is brought about most easily at a high temperature. It has also been noted that when manganese in the form of spiegeleisen or ferro-manganese is added to molten steel it bodily removes part of the sulphur; and it is thought by some metallurgists that a sulphide of manganese is formed and carried into the slag. Percy* has suggested that this action may throw some light on the origin in nature of the mineral helvite which, according to the formula of Rammelsberg,† is a sulphide of manganese (including iron) with silicate of beryllium and manganese (including iron and calcium). These indications of a more easy transition of manganese into the form of sulphide at high, than at low temperatures, may have had its influence in the rarity of manganese sulphides in deposits laid down under ordinary conditions, and the occasional occurrence of alabandite in metalliferous veins, where the temperature at the time of deposition may have been high.

In many of the silver deposits of the Rocky Mountains manganese oxides occur with the superficial oxidation products of the sulphides of other metals, and it has often been suggested that manganese also was originally in the sulphide form. This may sometimes be true, but it has not been proved; while in other cases, notably at Butte City, Montana, when the level is reached at which the lead, zinc, iron, and other metals pass into sulphides, the manganese passes into carbonate and silicate.

Deposition as silicate.—Iron is sometimes deposited at ordinary temperatures as the silicate known as glauconite, but manganese has not been found in a similar form. Glauconite is an olive-green mineral, and is essentially a hydrous silicate of iron and potash containing variable amounts of alumina, magnesia,

* Metallurgy; Iron and Steel, London, 1864.

† Handbuch der Mineralchemie, second edition, 1875, p. 460.

and other ingredients. It occurs in spherical or globular grains which often form beds of considerable thickness in various geologic horizons. The grains are supposed by some to represent fossil casts, and to have been formed by the combination of iron and potash with the silica from minute sponges which grew in the fossil cavities in which glauconite was subsequently formed.

Though manganese commonly exists as various silicates in the metamorphic rocks as well as in many mineral veins, and possibly also in the products of secondary alteration of other manganese minerals, yet it is not laid down in ordinary sedimentary deposits in that state, and as yet no manganese compound corresponding in form and mode of deposition to glauconite is known.

CONDITIONS OF DEPOSITION OF MANGANESE.—*General statement.*

It has been shown how manganese is taken into solution during the decay of the crystalline rocks and in what forms it is deposited again. It now remains to show under what conditions this deposition takes place, in other words, what stimulating causes bring about precipitation.

The solutions containing manganese begin to deposit their burden as soon as they are exposed to the oxidizing influences of the atmosphere. Thus the springs already mentioned on page 551 form a manganiferous sinter almost as soon as they issue from the ground, and this deposition continues along the courses of the outlets of the springs and the streams into which the springs drain, until the excess of mineral matter is laid down; hence the coating of manganese oxide on river pebbles. (See page 552.) The water during this kind of deposition, however, is rapidly moving onward and no considerable amount of ore is laid down in any one place.

When the metalliferous waters reach a more or less completely enclosed basin, however, such as a lake, bog, or coastal lagoon, their motion is impeded and they move sluggishly toward the outlet, thus allowing the oxidation and the resulting precipitation of a considerable part of their contents over local areas. The nearer such basins are to the source of the tributary

waters, other things being equal, the more of the metalliferous precipitates they will receive, as less will be lost in the intervening distance.

The manganese which escapes precipitation in these basins, or that of waters which have not passed through such basins, is carried on to the ocean, becomes greatly diluted with the sea water, and is deposited only when the local conditions are such as to bring about precipitation.

Hence three classes of manganese deposits may be distinguished: (1) those laid down at springs and in rivers; (2) those laid down in local, enclosed basins; (3) those laid down on the sea floor.

CONDITIONS OF DEPOSITION OF MANGANESE.—*In springs and rivers.*

The deposition of manganese at the outlets of springs and along rivers has already been described (pages 551–552) and does not require further mention. Ore deposited in this way is rarely accumulated in commercially important quantities.

CONDITIONS OF DEPOSITION OF MANGANESE.—*In local basins.*

The manganiferous contents of waters draining into shallow and more or less confined basins, such as bogs, lakes, or coastal lagoons, are rapidly oxidized, and as much manganese is precipitated as the intensity of the local oxidizing agencies can cause. In some cases the solutions are concentrated by evaporation, and thus a further precipitation is produced than would otherwise take place. The ore is laid down either as carbonate or as oxide, the form being determined by the local conditions of each area, as explained on pages 550–554.

Instances of deposition in shallow basins are seen in the manganiferous spathic ores of the Coal Measures and of some of the older rocks, in the ferruginous oxides of manganese sometimes found in the low coastal area of the Atlantic states, and in many deposits of bog manganese overlying the crystalline rocks in the northern states and in Canada. The manganese deposit in the calcareous tufa near Golconda, Nevada, (see pages 469–476.)

was also probably formed in a small, and more or less completely enclosed basin.

One of the great iron and manganese horizons of the Appalachians occurs between the Cambrian sandstone and the overlying limestone,* and is often associated with micaceous schist or hydromica slate. J. D. Dana,† in describing the ores of this belt, supposes that during the change of conditions of deposition from the schist to the limestone there was a time of long continued marshes, and that in these marshes the ores were deposited. Sometimes the schist horizon is represented by fine grained earthy sandstone; and both rocks indicate a condition of quiet water during sedimentation, strongly contrasted with the more rapidly moving conditions which accompanied the deposition of the coarser sandstone below. If it is granted that the ore was laid down in marshes and coastal lagoons, all the conditions necessary for the deposition of the oxides and carbonates of iron and manganese, and, in some cases, the sulphide of iron would be fulfilled.

It seems probable that a large number, if not most of the workable deposits of manganese in America were laid down in local basins by the processes just described. In some cases, however, noticeably in the deposits in the Lower Carboniferous limestone of Canada, there are evidences of a deposition on the sea floor.

CONDITIONS OF DEPOSITION OF MANGANESE.—*On the sea floor.*

General statement.—It is a simple matter to account for the deposition of manganese in local, enclosed basins where the metalliferous solutions, being only a comparatively short distance from the source of supply of their mineral contents and not having mixed with any great volume of water less rich in metalliferous matter, are in a more or less concentrated form. When these solutions once reach the open sea, however, they become greatly diluted and the precipitation of the mineral matter

* This statement must not be understood to mean that all the Appalachian manganese deposits which are in the area of sandstone or quartzite are necessarily of this horizon. Some have been proved to be so, others have not yet been determined. (See pages 376-379.)

† Amer. Jour. Sci., 3d series., Vol., XIV., 1877, p. 189.

requires the action of other agents in addition to those that have caused precipitation in local basins. It has been shown (pages 550–557) that most, if not all, bedded deposits of manganese ore were laid down as either carbonate or oxide, and therefore the precipitating agents must explain its deposition in those forms, and not as sulphide as might be the case with iron.

Precipitation by carbonate of lime.—It has been suggested that carbonate of lime, in the form of calcareous sediments on the sea floor or during its passage through the sea water, has acted as an arresting agent for many metalliferous deposits, by a simple process of replacement of the carbonate of lime and the substitution of the different materials in question. To a certain extent this might be applied to manganese, as it is a noticeable fact that those manganese deposits which exist in associations indicating an open sea sedimentation, often accompany limestones or calcareous shales.

Manganese exists in small amounts in almost all limestones, but it is only in rare cases that it forms deposits of economic value. Even in the limestones where it exists in quantities it is of very irregular distribution, sometimes characterizing the rock over considerable areas, at other times almost entirely disappearing or existing only as a small trace. On a calcareous sea floor, on which little or no mechanical sedimentation was going on, the long continued action of the extremely dilute solution of manganese compounds, might gradually cause a considerable replacement of carbonate of lime by carbonate of manganese, and thus produce considerable deposits of manganese ore. Such an action is not at all impossible, but if it had gone on unaffected by any other influences, the ore would be expected to be evenly distributed over large areas of limestone. This, however, as just stated, is not the case, and manganese-bearing parts of the limestone are frequently separated by several or even many miles of limestone containing practically no ore.

If the ore-bearing areas were comparatively close together, it might be supposed that segregation had caused the unequal distribution of the manganese, but, though segregation may often have had a certain influence over local areas, yet in many places

the intervening distance is so great and the other conditions are such, that the action of segregation alone, unassisted by other agencies, could not have caused the localization of the deposits.

Hence it becomes necessary to find, in addition to any possible action that limestone may produce, some local stimulating cause to explain the unusual precipitation in special localities.

Precipitation by marine plants.—It has been suggested in the case of the deposition of iron that a cause of localization existed in the presence of seaweeds on the sea floor. These often contain considerable quantities of iron as one of their inorganic constituents, and when they decompose, their mineral contents are laid down with the other sediments forming in that place, thus giving rise to more or less ferruginous deposits. It is possible that a similar cause may in some cases have brought about a deposition of manganese. This metal, however, enters into the composition of plants in much smaller quantities than iron, and it is as yet uncertain to what extent marine plants may have caused its deposition.* In several cases, however, its presence has been detected, and Maumené† states that it exists in the seaweed *Fucus serratus*. Professor Goodale‡ also describes its existence in the aquatic plant known as *Trapa natans*.

Precipitation by a local increase in the supply of manganese on the sea floor.—In view of the fact that no adequate precipitating agent presents itself to explain the deposition of considerable beds of manganese from the very dilute solutions in the sea water, it becomes necessary to suppose, at least in most cases, that there was a local source of manganese on the sea floor greater in some places than in others. Three possible sources for this local supply suggest themselves:

* Further difficulties with this mode of localization of manganese are mentioned on page 563.

† E. Moumené, Comptes rendus de l'Acad. des sci., t. XCVIII 1884, p. 1417.

‡ Gray's Botanical Text Book, Vol. II., Physiological Botany, George L. Goodale, p. 256.

(1) An excess of manganese in solution in certain areas of the sea.

(2) The presence of manganese in the mechanically suspended materials carried down from the land to the sea.

(3) Igneous materials thrown into the sea, either in the form of ejections from submarine vents, or of volcanic ash and dust from subaerial volcanoes.

(1) As regards the first possible source of a local excess of mineral matter, it may be said that Professor Chamberlin supposes such an action to have taken place in the formation of the lead ores of Wisconsin. In describing the process by which certain parts of the sea water were made richer than others in metalliferous solutions, he says*: "If any portion of the land surface yields more richly than elsewhere to the ocean, the waters of that portion will necessarily become richer in metallic salts. As such contributions are made, year after year, and century after century, they will presumably follow each other in a common course, borne by oceanic currents, and be brought within reach of depositing agencies in the same areas, being thrown down when *first* they came in contact with a competent reagent. Viewed in this light, in contradistinction from the idea of an ocean throughout which the metalliferous substances are uniformly diffused, the fact of localization is a necessary inference, instead of being a phenomenal enigma."

Chamberlin ascribes the precipitation of the lead ores partly to a process of segregation by marine plants and animals, similar to that already mentioned for seaweeds on page 561, and partly, to a powerful precipitating agent in the form of soluble sulphides derived from the decay of this organic matter. The local excess of lead in solution is proposed only to explain the deposition of the ore in one place and its absence in another, when equally favorable precipitating agents may have existed in both places. He supposes the ore to have been deposited as sulphide, in a finely disseminated state in the limestone which was forming at the same time, and to have been subsequently segregated in crevices.

* T. C. Chamberlin, Geology of Wisconsin, 1873-79, Vol. IV., p. 531.

A local excess of manganese might be supplied in the sea water in a manner similar to that suggested by Professor Chamberlin for lead, but in explaining the deposition of the ore the same difficulty is encountered as that already mentioned, that is, the lack of a suitable precipitating agent. The theory of the precipitation as sulphide is applicable to lead and many other metals, and even in the case of manganese it is not impossible that small quantities of sulphide might be formed, * but in the large sedimentary deposits of manganese there is no evidence that the ore was originally in the sulphide form. (See pages 554–556.) Here again, in some places, carbonate of lime on the sea floor may have acted as a precipitating agent and may have caused local deposits, but as yet the evidence as to what extent this action may have taken place is wanting. It may be mentioned, however, that the manganese ores of the Lower Carboniferous limestone of New Brunswick and Nova Scotia, frequently contain fossil casts which have been more or less completely converted to manganese ore. Such ore is often highly calcareous and has the appearance of being a fossiliferous limestone in which the carbonate of lime has been partly replaced by manganese. Elsewhere in the same region, however, nodules and layers of ore are found in a state of great purity and apparently free from organic remains. Some of these pure deposits have been formed by the solution and re-deposition of the manganese (see pages 531–538), but others seem to occupy the same position in which they were originally laid down. †

(2) As regards the second possible cause of a local excess of manganese on the sea floor, that is, the presence of manganese in the mechanically suspended materials carried down from the land, there seems to be a possibility that it may, in some cases, have played a small part in the accumulation of manganese deposits. The manganese might be either in the form of particles of oxide which had so far escaped solution, or of small fragments

* It has been suggested by Chamberlin, (Geology of Wisconsin, Vol. IV., 1873-79, p. 391) that the small quantities of oxide of manganese now found with the lead ores may have been originally in the sulphide form.

† The various views on the origin of Canadian manganese deposits are discussed on pages 567-568.

of the as yet undecayed silicate. A subsequent decomposition of the latter would give rise to oxide of manganese, which would be taken into solution and segregated in the form of carbonate or possibly in some cases as oxide. Manganese oxides, however, are so rapidly taken into solution by acidulated surface waters, and the silicates are so readily converted to oxides, that the supply of manganese in the form of mechanical sediments has probably not played any important part in the formation of deposits of manganese ore.

(3) The third possible source of a local excess of manganese on the sea floor, that is, a supply of igneous materials thrown into the sea, seems in some cases to have played a part in the formation of manganese deposits.

Igneous rocks contain manganese mostly in the form of silicates, which, when exposed on the surface to atmospheric influences, decay in the same way as those in all crystalline rocks (see pages 546–548), and give up any manganese that they may contain. This is dissolved by surface waters and the metalliferous solutions are carried off in the manner already described on page 547. When, however, igneous materials are thrown into the sea from submarine vents, or when volcanic ash from subaerial volcanoes falls into the sea, there may exist a ready source for the local accumulation of manganese. If the igneous material were thrown into the water directly, it would undergo a very rapid decomposition and an equally rapid liberation of the metallic oxides; if it were in the form of ash or dust from subaerial volcanoes, the decay would be slower, but would eventually supply very considerable quantities of metallic salts. The collection and segregation of these decomposition products on the sea floor might readily give rise to considerable deposits of manganese ore. How important this cause of local accumulation may have been in the past is uncertain, but, judging from the indications at the present time, there seems to be reason to suppose that it may occasionally have been an effective one.

The explorations of the sea bottom made during the voyage of the Challenger, and other later expeditions, have shown a remarkable distribution of manganese oxide which, it has been

suggested, may have been derived from the decay of igneous materials on the sea floor. The manganese occurs * as peroxide in grains, concretions, nodules, or aggregations, varying from microscopic particles to masses several inches in diameter. It is found most abundantly in the deep-sea clays, but it also occurs at all depths over 500 fathoms. It is especially plentiful in the Globigerina and Radiolarian ooze; and when in the form of microscopic pellets, it gives the clay or mud a characteristic deep cholocate color. It is usually found incrusting or filling the cavities of organic remains, such as shark's teeth, shells, sponges, corals, etc. In places the sea bottom and everything on it is coated with manganese. Murray describes a number of different forms of deposition:

(1) Nodules of a blackish-brown color throughout and composed of concentric layers, as shown by the presence of films of red clay.

(2) Concentric layers of manganese oxide surrounding a nucleus of pumice. Sometimes the pumice is deeply impregnated or even completely replaced by manganese. Pieces of bone also sometimes form a nucleus and are often replaced in the same way. The compact bone of the tympanics of cetaceans appear not to be altered so rapidly as other bones, and hence the possible cause of the great abundance of the former in many localities.

(3) Concentric layers of manganese oxide surrounding shark's teeth (from one to four inches across the base) in an incrustation sometimes nearly an inch thick. A siliceous sponge (*Farrea*) was found imbedded in a crust of manganese oxide two inches thick.

(4) Nodules of manganese oxide containing in the center a mass of red clay, or a mottled yellow or green substance with agate bands, and containing Globigerina, in which the carbonate of lime has been replaced by silicate. The yellow or green nucleus either cuts like cheese, or is hard, brittle, and has a conchoidal fracture.

* John Murray, Proceed. Roy. Soc. London, Vol. XXIV., pp. 528-529.

(5) Large flat aggregations probably representing hardened parts of the sea bottom.

(6) The Globigerina shells and Radiolaria are sometimes covered by specks of manganese oxide. In the former the manganese is deposited in the substance of the shell.

(7) Southwest of the Canary Islands, at a depth of from 1,100 to 1,575 fathoms, there were found large pieces of a branching Gorgonoid, deeply coated and impregnated with manganese.

(8) In 670 fathoms, off the Desertas, dead shells, pieces of coral, Polyzoa, etc., were coated with a film of peroxide of manganese. The same thing was observed in shallower water.

(9) In some of the layers of Radiolarian ooze and in other deposits, manganese was found to be abundant and rare in alternate strata.

The localities in which manganese was found most plentifully were: off the Canary Islands; in the Mid-Atlantic between the Canary and Virgin Islands; southwest of Australia; north and south of the Sandwich Islands; north of Tahiti; and in the South Pacific in the course between Tahiti and Valparaiso.

Sir C. Wyville Thomson * in describing manganese nodules dredged up during the Challenger Expedition, on the trip between the Bermudas and Madeira, at a depth of about 2,850 fathoms, says: "The concretionary masses to which the barnacles adhered were irregular in form and size. One, for example, to which a large *Scalpellum* was attached, was irregularly oval in shape, about three centimeters in length and two in width. The surface was mammillated and finely granulated, and of a dark brown color, almost black. A fracture showed a semi-crystalline structure; the same dark brown material arranged in an obscurely radiating manner from the center, and mixed with a small quantity of grayish-white clayey matter. This nodule was examined by Mr. Buchanan, and found to contain, like the nodule dredged in 2,435 fathoms at Station XVI., 700 miles to the east of Sombrero, a large per-

* The Atlantic, a preliminary account of the general results of the exploring voyage of the H. M. S. Challenger during the year 1873, etc., Vol. II., pp. 14-15.

centage of peroxide of manganese. Some other concretionary lumps were of a gray color, but all of them contained a certain proportion of manganese, and they seemed to be gradually changing into nodules of pyrolusite or wad by some process of infiltration or substitution."

Murray states* that copper, cobalt, nickel, and iron are found in some sea bottom clays, suggesting meteoric or cosmic dust in these deposits. He also shows that the great numbers of tympanic bones and other animal remains on certain parts of the sea floor, as well as the deposition of manganese, which he supposes to be a very slow process, represent the accumulation of ages in an area where mechanical sedimentation has been very slow or totally inactive. He suggests the possibility of manganese being found most plentifully where large quantities of augitic lava occur. The manganiferous silicates in such lava might readily, by their decomposition, supply materials for the incrustations of oxide of manganese.

It has been suggested by Sir William Dawson† that the manganese deposits in the Lower Carboniferous marine limestone of Nova Scotia may have been derived from the decomposition of the debris of the contemporaneous igneous vents which produced the traps of that period.

Mr. E. Gilpin, Jr.,‡ recognizes this same source of manganese as possible in the Nova Scotia deposits, and also suggests the possibility of an additional source from the older strata bordering the Carboniferous sea.

Mr. G. F. Matthew, of the Geological Survey of Canada, in a letter kindly written in answer to inquiries by the writer, has also suggested a source from igneous materials for the manganese deposit in the Lower Carboniferous limestone at Markhamville, New Brunswick. He recognizes the possibility of a deposition and segregation of the manganese in a manner analogous to that at present known to be going on in many ocean bottoms, though it was laid down in shallower water than many of the modern

* Proceed. Roy. Soc., London, Vol. XXIV., p. 532.

†Acadian Geology, supplement to second edition, p. 51.

‡ Trans. Roy. Soc. Canada, May 22, 1884, p. 18.

deposits. In support of this possible source from igneous materials, he points out the fact that dolerite, felsite, and trap are found around the Carboniferous basin of New Brunswick, especially on the northern side.

It seems possible that a certain amount of manganese might be afforded by the vapors from igneous vents. It is a well known fact in the metallurgy of manganese, that in smelting the ores of that metal, a noticeable quantity of it appears to be volatilized. This conclusion is arrived at by the fact that not only do the analyses of the slag and the reduced metal show a total of manganese less than that in the original charge of the furnace, but also that the gases which pass off are found to contain a very noticeable percentage of that ingredient. P. Jordan* shows that in the manufacture of ferro manganese at the St. Louis furnaces near Marseilles, France, often as much as 10 per cent of the manganese can not be accounted for either in the cast metal, in the slag, or in the dust mechanically carried out by the gases from the furnace. He also shows that an analysis of the gas proves the presence of manganese, that the gas often has a rose color, and that it deposits on the surrounding objects an incrustation containing a considerable proportion of manganese. From these and other facts he concludes that the manganese which is lost in the furnace is volatilized; and he further strengthens this supposition by showing that, when ferro-manganese is fused in crucibles at high heats, the same loss in manganese takes place.

The different chemical forms which manganese might have under conditions of volatilization from a volcano are somewhat uncertain, but it is possible that, if submarine volcanoes should throw off such gaseous materials, a certain quantity of manganese might then be supplied to the sea water, and through its medium to the sediments on the sea floor. This might also account for manganese in some ocean sediments where no visible volcanic debris is present.

In conclusion it may be said that the formation of large

*Comptes rendus de l'Acad. des sci., t. LXXXVI, 1878, pp. 1874-1877.

deposits of manganese ore on the sea floor by any or all of the methods already described, is probably a much rarer process than the deposition in local basins. There is undoubted evidence that an important deposition is at present in progress on many sea floors, and the general opinion, as already cited, of those who have studied the deposits in the Lower Carboniferous limestone of New Brunswick and Nova Scotia, seems to be that these also represented an ocean water sedimentation. In many other places, however, especially in some of the most important localities in the United States, there seems to be reason to suppose that the deposition of the ore took place in local basins. These basins were probably often in the form of coastal lagoons and possibly in some places represented simply coastal shoals. J. D. Dana suggests such a mode of origin for one of the most important ore belts in the Appalachian Mountains (see page 559), and, as shown later in this chapter, there seems to be reason to suppose that the deposits of the Batesville region of Arkansas had a somewhat similar origin.

THE ASSOCIATION AND SEPARATION OF MANGANESE AND IRON.

General statement.—One of the most noticeable features of manganese deposits is the almost invariable presence of iron. Sometimes, in fact, iron forms by far the larger part of the deposit, and manganese occurs only as a subordinate constituent. Nowhere is this association seen better than in the manganese and iron deposits at, or near the contact of the quartzite* and the overlying limestone and shale on the northwestern flanks of the crystalline rocks, from the Green Mountains of Vermont to the Blue Ridge of the southern states. Sometimes the two metals are intimately associated in an ore of more or less homogeneous composition, while at other times the manganese occurs as interbedded layers, pockets, or nests in the iron ore; or else, more rarely, the

* This quartzite has, in some cases, been referred to the Cambrian age and in others to Silurian. The exact horizon of the bed is not of importance in the present discussion, as the point which it is desired to bring out is that, whatever its age, it was laid down near the flanks of the crystalline rocks. For further details concerning it see pages 376–379.

two ores occur in separate deposits in different places along the same ore-bearing horizon.

Causes of association of iron and manganese.—It has already been stated that iron and manganese are generally derived from the decay of the same crystalline rocks and that they are both taken up in solution together by acidulated waters. As under many conditions both manganese and iron are precipitated by the same influences, their frequent association is what would be expected. Moreover, it is a well known fact that isomorphous substances have a strong tendency to combine in a homogeneous mass and to crystallize together in different proportions. Carbonates of iron and of manganese are isomorphous with each other, and hence a possible cause of the intimacy of their association, such as is seen in almost all spathic iron ores. The oxidation of such an admixture would give the common form of an intimately combined iron and manganese ore.

Since there is more iron than manganese in the crystalline rocks, the surface waters draining from areas of such rocks, except in special cases, contain the metals in a similar proportion. Hence the isomorphous carbonates deposited from the solution have a larger percentage of carbonate of iron than of carbonate of manganese, and the resulting oxides contain the two metals in the same proportion, thus giving rise to the common low-manganese iron ores characteristic of the Appalachian Valley.

The oxides of manganese and iron, however, are not isomorphous, and therefore when they are precipitated together, as in bog deposits, the association is merely mechanical, due to the fact that under certain conditions the oxides of both metals are precipitated in the same place.

Causes of separation.—When manganese and iron ores occur as more or less separate deposits, it becomes necessary to suppose the action of influences different from those which cause the deposition of both together, and such influences are to be found in the different modes of precipitation, under certain conditions, of the two metals.

Fresenius* states that, at the warm springs of Kochbrunnen,

* Jahrb. des Vereins Naturkunde in Herz. Nassau, Vol. VI., p. 160 (Bischof.)

at Wiesbaden, the waters, on reaching the surface, first deposit hydrous peroxide of iron, and farther on carbonates of manganese, lime, and magnesia. This not only points, as suggested by Bischof, to the well known fact that carbonate of iron is more rapidly oxidized than carbonate of manganese, but it also leads to the belief that the bicarbonate or other salt of iron in the water is more easily oxidized than the manganese salt.

An action somewhat similar to that described by Fresenius* readily explains the occurrence of iron and manganese ores in distinct, alternating beds. Suppose the metalliferous solution to be confined in a shallow basin: the iron, becoming oxidized on the surface, sinks to the bottom, possibly in some cases to be converted there to the simple carbonate by organic matter. Further oxidation precipitates oxide or carbonate of manganese on top of the iron. A renewed supply of surface water brings more solutions of iron and manganese, or else the evaporation of the water in the closed basin concentrates the materials which have not yet been precipitated. In either case, there is a further precipitation of the ores.

This action necessitates the supposition of an intermittent supply of metalliferous solutions, and such a condition might readily take place in local basins, such as coastal lagoons, which are often dependent for their supply of water on the changes of season and the sudden fluctuations of the weather. In many cases, however, the supply is constant, and the deposition of both iron and manganese goes on continuously, and so nearly at the same time that a comparatively homogeneous manganiferous iron ore is formed. By these various conditions of deposition, the series, so often seen in the Appalachian Valley, of iron ore containing interstratified beds and pockets of manganese ore, could be produced.

If the waters from which the precipitation took place were moving, the iron and manganese, owing to the difference in oxidability as stated above, would be laid down in different places,

* Bischof suggests that the action described by Fresenius causes the separate deposition of manganese and iron; and also that it explains the occurrence, in regions of both ores, of the largest deposits of manganese ore where the iron ore contains least of that ingredient. (Elements Chem. and Phys. Geol, Vol. III., pp. 531-532.)

resulting in the formation of deposits of pure iron ore and deposits of pure manganese ore, occupying different positions along the plane of the same geologic horizon. Such occurrences are seen in the iron region of the Appalachians, where there are often found, in different places along the same ore belt, deposits of iron and deposits of manganese in positions similar with relation to the enclosing rocks.

These conditions of moving water might also cause the interstratified condition of the two ores already described in still water deposits: this would result if iron were deposited in a certain place at one time, and if later, on account of some increased facility for oxidation, iron were deposited before it reached that place, and the manganese, being less easily precipitated, were carried on and laid down upon the first deposit of iron.

When the two ores are deposited in a homogeneous mass, as already described, a subsequent separation might possibly be brought about by a process of segregation.

Another process of separation in nature of iron and manganese might take place by the formation of sulphide of iron. It has already been shown that iron is sometimes deposited as sulphide and later oxidized in the same manner as the carbonate. Manganese, on the other hand, is rarely found as sulphide, and there is reason to think that the sulphide never represented the original form of any large sedimentary deposits of manganese ore. (See pages 554–556). It seems probable, therefore, that from the solution of iron and manganese derived from the crystalline rocks, the iron might, where the conditions were favorable, be precipitated as sulphide, and the manganese carried on in solution to be deposited elsewhere as carbonate. Subsequently, the oxidation of the ores would give rise to oxide of iron from the sulphide, and oxide of manganese from the carbonate; and the two ores, though occurring at the same horizon, would be separated by a greater or less distance.

After the deposition of the sulphide of iron, the conditions might change and permit the deposition in the same place of the carbonates of iron and manganese together. This is an easy case to imagine, and where such a deposit was exposed to surface

influences, the resulting product would be oxide of iron from the underlying sulphide, and a manganiferous iron oxide from the overlying isomorphous carbonates; hence another possible cause of the frequent occurrence of interstratified manganese ores and manganiferous iron ores. It is possible, also, that after the solution of iron and manganese had been freed from the former by precipitation as sulphide, the carbonate of manganese might be carried on and laid down on a previous deposit of iron sulphide, and when such a combination was oxidized, the result would be interstratified but distinct beds of oxide of iron and oxide of manganese.

By supposing the iron sometimes to be deposited in sea water as glauconite, a manner in which manganese is not laid down (see page 557), a further means of separation of the two metals would be supplied.

Thus by alternating the conditions of the deposition of manganese and iron in different forms, a great variety of methods of association and separation of the two ores can be produced.

SECONDARY CHEMICAL AND PHYSICAL CHANGES IN MANGANESE DEPOSITS.

General statement.—It has been shown how the ores of manganese were originally derived, how they were transported, and in what forms and under what conditions they were deposited. By these means the Paleozoic and younger rocks acquired their contents of manganese, and by the same means the formation of manganese deposits is going on at the present time. Rocks of later ages may owe a part of their manganiferous materials to the store in the Paleozoic or even younger sediments. Hunt* has shown, however, that iron is more plentiful and more regularly distributed in the crystalline than in the later rocks, where it has become localized by agencies already described, and therefore the former rocks offer a much more abundant and ready source of supply. The same may also be said of manganese.

* T. Sterry Hunt, Chemical and Geological Essays, 1875, p. 22.

In some places the ores were laid down without any admixture of foreign materials, while in others calcareous, siliceous, or argillaceous sediments were deposited at the same time. The manganese contents of the beds were largely chemical precipitates; the earthy materials were mechanical sediments. The predominance of one class or the other, therefore, depended on the local conditions of deposition: where the waters tributary to the basin in which the deposits were being laid down contained metalliferous solutions, but carried no materials in mechanical suspension, then beds of more or less pure ore were formed; where the waters carried earthy materials, these were deposited with the chemical precipitates.

Hence there may exist beds of pure ore, or else beds of limestone, shale, slate, sandstone, etc., containing manganese in a finely disseminated state and in greater or less quantities. Later segregation has sometimes collected the disseminated ore and formed comparatively pure metalliferous deposits.

The chemical changes which have gone on in manganese deposits since their original deposition and segregation, vary greatly in different places, and depend largely on the original condition of the ore and the enclosing rock, and on the influences that have been brought to bear on the deposits since their formation. For this reason the changes have been discussed in connection with the occurrence of the ores in each special region, and the reader is referred to the foregoing chapters of this report for further details*. The present treatment will be more of the nature of a summary of the results reached than a repetition of what has already been discussed.

Decay of the manganese-bearing rocks.—Decomposition has, in many places, affected the ore-bearing strata and has converted them into clay, which often, though not always, carries the ore in the same, or nearly the same form in which it originally existed in the rock.†

* For the secondary changes in the Batesville region see chapter VIII.; in southwestern Arkansas, pp. 325-326; in the Appalachian region, pp. 385-388; in Texas, pp. 437-439; in the Rocky Mountains, p. 453; in Nova Scotia, pp. 531-538.

† In places, however, secondary chemical action has considerably altered the mode of occurrence of the ore, as explained later in this chapter.

The manganese-bearing belt of the Appalachian Valley, extending intermittently from northern Vermont to Georgia, represents such a deposit. The Batesville manganese region of northern Arkansas also represents a similar occurrence. In the latter region, however, the original rock was horizontal or almost so, while in the Appalachians the rocks stood at high angles; hence the products of decay differ considerably in their mode of occurrence in the two regions: while in the Batesville region the ore deposits represent isolated areas resting on underlying rocks, in the Appalachian region they form a well defined belt, occupying certain topographic and geologic positions throughout the Appalachian Valley.

In the Batesville region the evidence of decay in situ is too evident to admit of discussion, but in the Appalachian region it was formerly supposed that the clay outcrop of the decomposed ore stratum represented a secondary diluvial deposit, laid down in the valleys and impregnated with manganese and iron by solutions derived from the higher land. In the Geology of Vermont, 1861, E. Hitchcock suggests that the iron and manganese belt of the Appalachian Valley represents a Tertiary deposit, extending along the Appalachian Valley from northern Vermont to Alabama. In the map of Vermont accompanying the above mentioned work, a strip representing the metalliferous horizon, running south from Moncton through Brandon to Bennington, is colored as Tertiary. Hitchcock based his ideas on the discovery of true Tertiary fossil fruits and plants in the Brandon lignites, and as iron and manganese were found in the same locality, he considered them also of Tertiary age. Reasoning from this evidence, he placed the continuation of the iron-bearing belt in other parts of Vermont, where lignite did not occur, in the Tertiary.

It has since been shown that the Brandon beds represent only a local Tertiary area, formed mostly of the rearranged materials from the Paleozoic beds, which probably underlie it; and that in most other places in western Vermont, and in the Appalachian Valley in general, the ore-bearing clay occupies the same relative position that it

occupied when it was in the form of a solid rock. The latter idea was suggested for certain Pennsylvania iron ores by R. M. S. Jackson in 1838.* In 1865 it was favorably discussed by J. P. Lesley,† in 1867 by Benjamin S. Lyman,‡ in 1874 by Dr. T. Sterry Hunt,§ and by Dr. Persifor Frazer. ||

The immediate outcrop of the ore-bearing stratum, or rather the surface deposit covering it, may consist of the re-arranged residual products of the underlying bed brought into their present form before, during, or after Tertiary times, and local occurrences of lignite in Pennsylvania are mentioned in chapter XV., under the description of the manganese ores of Vermont. The mass of the ore deposit, however, generally represents the decomposition, in situ, of the original ore-bearing rock. No better evidence of this can be advanced than the descriptions of localities given in previous chapters. In many places, the ore-bearing clay contains masses of rock with fragments of ore. Such masses are irregular, semi-decomposed, and blend into the clay without any sharp lines of separation. The ore in them is the same as that found in the clay, and it is sometimes possible to see a part of a pocket of ore in the clay and a part in the fragments of rock. Not only this, but in many places manganese can be seen in the solid rock bordering the ore-bearing clay, and the same blending is observable as that between the rock fragments and the clay; thus leaving no doubt that the fragments and the clay belong where they are now found, and represent the undecomposed parts of the original stratum.

If further evidence is needed, it is seen at South Wallingford, Vermont: here the Cambrian quartzite, standing

* J. P. Lesley, Second Geol. Survey of Penn., Report A, p. 83. In 1837 C. U. Shepard had announced, in his Report on the Mineralogy of Connecticut, a similar theory of decay in situ for certain iron ore deposits in the crystalline rocks of western Connecticut. (T. Sterry Hunt, Trans. Amer. Inst. Mng. Eng., Vol. III., 1874-5, p. 419). Jackson's theory for ores in the Paleozoic rocks, however, is said to have been advanced independently of Shepard's theory.

† J. P. Lesley, Proceed. Amer. Philos. Soc., Vol. IX., 1865, pp. 466 et seq.

‡ Proceed. Amer. Assoc. Adv. Sci., 1867, pp. 114-117.

§ Trans. Amer. Inst. Mng. Eng., 1874-5, Vol. III., pp. 448-421.

‖ Second Geol. Surv. Penn., Report C, 1874, p. 142.

almost vertically, forms a high ridge on one side of the ore-bearing stratum, and the overlying limestone occupies the other side, on the lower slope. The ore-bearing stratum comes between them, and causes, by its easy erosion, a slight flat on the slope of the hill. In mining brown hematite and manganese ore, a tunnel has been run for about 1,700 feet into the hill, mostly along this deposit, and numerous drifts have demonstrated the existence of quartzite on one side and limestone on the other, thus proving the interbedded character of the deposit. Similar instances can be seen throughout the Appalachian Valley from Vermont to Georgia, and though the actual mode of occurrence of the ore is sometimes obscured by the wearing down of the soft ore-bearing stratum and its consequently occupying the low places, yet wherever the nature of the deposit can be made out, it is that of a stratum interbedded with the associated rocks; or else it is the surface outcrop of such a deposit rearranged by surface agencies in more or less nearly horizontal layers.

It is probable that in many places the surface erosion of the residual clay may have caused a mechanical concentration of the masses of ore in the upper part of the deposit, and may thus have rendered that part of the deposit richer in ore than the lower part, but such action is entirely superficial. Its effect, however, may often be to render the upper part of the deposit workable at a profit, while in the lower part the ore in many cases may be too scattered to be profitably mined.

The original ore-bearing rock has in some places not undergone decay, and the ore still occurs in place in it on the surface. At the Cabell mine in Virginia, in the Cebolla Valley of Colorado, in the Coast Ranges of California, and many other places, manganese is found in place in the original rocks. In the Cave Spring region of Georgia manganese occurs both in situ in chert and cherty limestones, and also in the residual clay from the decay of those rocks. In

southwestern Arkansas manganese occurs in massive novaculite, while in northern Arkansas, though the ore is generally in the residual clay of Silurian limestone, it is sometimes seen in place in that rock. In New Brunswick and Nova Scotia manganese has been mined in both the overlying residual clay and the underlying solid limestone. Between the condition of an unaltered ore-bearing rock and the condition of complete decay, there are all gradations in the amount of decomposition and consequently in the extent of the residual, ore-bearing clay.

As a result of the variety of conditions under which the decay of the ore-bearing rocks takes place, the depth of the decay varies considerably in different places and in different rocks. In the Batesville region of Arkansas a highly crystalline manganese-bearing limestone, lying horizontally and sometimes considerably over a hundred feet in thickness, has often been completely decomposed. The more siliceous rocks of other regions have also often decayed to considerable depths. At the Crimora mine, in Virginia, the clay, which has probably resulted from the decay of a more or less shaly material, is over 276 feet thick; while in some of the mines in Georgia, though the shafts have not been sunk so deep as at Crimora, a very considerable thickness doubtless exists. A shaft at the Chumler Hill mine, in the Cartersville region of Georgia, has been sunk over 80 feet without reaching the bottom of the clay.

Agents of decay of the manganese-bearing rocks.—It is a noticeable fact that the stratum carrying the manganese ore is often decomposed to a much greater depth than strata of similar rocks, in the same neighborhood, exposed to the same atmospheric conditions, but not carrying ore. This fact requires the supposition of an agency of decay in the ore-bearing stratum additional to those agencies that have acted, or are acting in the other rocks. It seems possible that this factor is in many cases supplied by the ore itself, or by the materials accompanying the ore.

J. D. Dana,* in describing the iron ores of the Appalachian

* Amer. Jour. Sci., 3d series, Vol. XIV., 1877, p. 138-139.

Valley, has suggested the influence of carbonic acid and sulphuric acid, derived respectively from the oxidation of the carbonate and the sulphide of iron, in the decay of rocks. Supposing the manganese to have been originally in the form of carbonate and subsequently converted to its present oxide form, it seems probable that the carbonic acid liberated from it in the same way as from iron carbonate, may have had an important effect in the decomposition of the enclosing rock.

In the case of the manganese-bearing limestone of the Batesville region in Arkansas, as explained on pages 178 to 179, a cause of the exceptionally extensive decay in the parts of the limestone containing ore may exist in the presence of earthy materials. Such materials are much more abundant in the ore-bearing parts than in the barren parts of the rock, and they afford a porosity which allows a freer percolation of surface waters and hence a more rapid decay of the rock than elsewhere.

The contraction of those ores which were laid down as carbonate, when they are transformed to oxide, gives rise to cavities and to a generally porous character observable in many manganese ores. This change in physical character would facilitate the percolation of water and hence the decay of the enclosing rock.

The inclination of the strata in the various manganese regions has not been without its effect in hastening decay, as the steeply dipping strata afford, by their upturned edges, a more accessible entrance for surface waters, and consequently a more rapid and deeper decay than low-dipping strata, which tend more to shed the surface waters. This influence, however, is shared by the ore-bearing rock in common with the other rocks in the immediate neighborhood.

Mode of decay of the manganese-bearing rocks.—The causes of decay in the crystalline rocks, from which the manganese was originally derived, are the breaking up of silicates and the solution of the resulting oxides. (See pages 547–548.) In the clastic rocks which now contain the ore derived from the crystalline rocks, the cause of decay, except where silicates have been formed again by metamorphism, is simply the bodily

removal in solution of certain constituents of the rocks, generally carbonate of lime and greater or less quantities of metallic oxides, without the intermediate process of the chemical alteration of certain mineral ingredients.

When the ore-bearing stratum is a limestone, the process of decomposition is simply the removal of carbonate of lime in solution and the concentration of the masses of ore and the residual clay, the latter representing the insoluble impurities of the original rock. Such is the case with the manganese deposits of the Batesville region and some of those of the Appalachians. Sometimes the manganese-bearing stratum is largely composed of chert, usually, however, more or less calcareous. An illustration of this is seen in the deposits in the Knox dolomite of the Cave Spring region of Georgia. In such cases the decomposition goes on by the removal of the disseminated carbonate of lime and the disintegration and possibly the partial solution of the cherty material. When the ore-bearing stratum was originally composed of shale, the decomposition likewise goes on by the solution of any finely disseminated carbonate of lime that may be present as well as of the metallic oxides. When manganese is found in sandstone or quartzite, the rock in immediate contact with the ore is usually made up of a fine grained, earthy material, which, on exposure, disintegrates into a more or less sandy clay.

From whatever source the clay has been derived, it is usually highly siliceous on account of the more or less complete removal of the basic components of the original rock; and is frequently brilliantly mottled red, brown, yellow, purple, and black, by the presence of certain quantities of iron and manganese in different stages of oxidation and hydration. Sometimes it is pure snow-white.

Chemical action on the manganese ore.— The ore itself has been considerably affected by chemical action during the secondary decay of the enclosing rock. The first change that goes on is the conversion of any carbonate that may be

present into oxide,* thus completely changing the chemical nature of the ore. The subsequent changes, however, occasionally have a much greater influence on the physical nature and mode of occurrence of the ore: though in many places the ore in the clay seems to occupy much the same relative position that it did in the original rock, yet in some places it has often been dissolved, and the solution has either been re-precipitated in another position in the same deposit, or has mixed with surface waters and been entirely removed from the deposit. Such an action is caused by acidulated surface waters and often tends to segregate the ore in nodular and stalactitic forms.

Professor N. S. Shaler,† in discussing the origin of certain iron ores in Kentucky, Ohio, and other places, points to the fact that many of them overlie limestone, protruding into it in very irregular bodies, and that they are themselves overlain by more or less ferruginous shales and other rocks. He supposes that the iron was removed from the overlying rocks in solution and carried down into the limestone, where it was deposited by replacement as carbonate, subsequently altered by oxidation and hydration, and converted into limonite. The irregular manner in which the metalliferous solutions percolate through the limestone would account for the uncertain extent of many brown hematite deposits, and for the fact frequently observed that they appear to cut directly across the bedding of the enclosing limestone. Professor Shaler also shows, however, that in many places in rocks other than limestone, such as shales etc., a segregation of carbonate of iron in the form of

* G. Bischof thinks (Elements of Chem. and Phys. Geol., Vol. III., pp. 508 and 530) that the sesquioxide of manganese which occurs in manganese ores has been derived from deposits of carbonate of manganese, while the peroxide has been produced directly from the solution of the carbonate and also from the peroxidation of other oxides. The time available for the present report has not permitted a further study of this subject, nor an investigation of the various possible transitions of certain mineralogical forms of manganese oxides into others, such as are illustrated in the peroxidation of manganite into pyrolusite, and the possible genetic relation of the two peroxides, pyrolusite and polianite.

† Kentucky Geological Survey, Report of Progress, Vol. III., New Series, 1877, p. 164.

nodules or larger bodies frequently takes place without the agency of replacement of carbonate of lime.

A segregation by replacement of limestone may also have sometimes taken place with manganese deposits. When, however, the waters containing manganese in solution percolate through a siliceous clay, such as is represented by the residual product of most of the ore-bearing rocks, the manganese often undergoes a segregation without this intermediate process of replacement. The percolation of manganiferous solutions in the accompanying clay is going on at the present time in many places in the Valley of Virginia, especially at Crimora and at Lyndhurst. It frequently turns the clay black in spots, or forms stringers of ore in cracks, giving rise to a popular idea that the amount of manganese is growing. As a matter of fact, however, the ore is not increasing in quantity, but is simply changing position in the clay bed, by being first dissolved by carbonated waters, carried in solution until the waters happen to reach a place where their contents are oxidized, and then deposited again. This accounts for the presence of manganese in open parts of the enclosing bed and in cracks and cavities. The digging of shafts and tunnels, or the erosion of creeks in the ore-bearing clay, gives such solutions, when they reach the side of the excavation or the banks of the creek, the chance to become oxidized; and therefore the manganese is often deposited in such places. Though this process of solution and re-deposition, when both actions are confined to one stratum, does not actually increase the total amount of ore present in that stratum, yet it has often been the means of segregating ore which was originally minutely scattered throughout the deposit, and laying it down in bodies of workable size.

Brecciation in manganese deposits.—One of the most noticeable features of many manganese deposits is the brecciation often observed in the accompanying rock, which is frequently broken up into angular fragments and cemented by oxide of manganese. The rocks seem to have been broken in place, and it can often be seen that if the cementing material were removed, the angles of each fragment would fit into the angles of the

adjacent fragments; in other words, if the ore were removed, the separate fragments of rock would fit together and make a solid continuous mass, just as do the individual pieces of mosaic work.* This would not be the case were the breccia formed by the indiscriminate mixing of rock fragments, and it points clearly to the fact that the breaking process has gone on in place in the rock.

This brecciation in situ has doubtless been produced by different causes in different places: in some cases it is probably due to the crushing of the rock during folding, and the subsequent cementing of the fragments by mineral matter. Such crushing would tend to be more or less marked in certain strata which had less power to resist fracture by lateral pressure than the associated strata; but in the case, such as sometimes occurs, of a brecciation along a certain horizon in an apparently homogeneous stratum, an additional explanation is needed for the localization of the phenomenon. Here an initial fracture or jointing of the rocks may have been caused by lateral pressure, and may have been common to the whole stratum. These cracks may have been forced open along a certain horizon in the stratum by the segregation and crystallization in them of mineral matter formerly finely disseminated through the special horizon. Such an effect in the mineral matter would undoubtedly be at least partly due to capillary action, which itself might cause a powerful expanding force in the absorbing rock. In this last process the rock might be broken again in still other directions than those of the original joints, and thus give rise to a minutely brecciated stratum.

It also seems possible that brecciation of this kind may in some cases be strictly superficial, and that the expansion of the crevices occupied by the ore may have been assisted by frost and other surface agencies. Each, therefore, of these expanding forces, that is, crystallization, capillary action, and frost has probably had its influence in forcing open the fractures caused by folding or other forces acting on the rock.

* This kind of brecciation is not confined to manganese deposits, but is seen in many iron, zinc, and other metalliferous deposits.

In almost all such cases the mineral matter of the breccia has probably come directly from materials disseminated either in the fractured bed itself or in the immediately associated beds, though in some rarer cases spring waters may have acted as a source of supply.

In the manganese region of Hants county, Nova Scotia, the ore frequently occurs with, and sometimes cements the fragments of a highly brecciated dolomitic limestone. This bed underlies the great gypsum and anhydrite deposits of that region, and the brecciation, in this case, appears possibly to have been caused by the conversion of anhydrite into gypsum. (See pages 531-538).

Action of metamorphism on manganese deposits.—It has been shown that the action of the surface decay on manganese deposits has a great influence on the nature of the ore and the enclosing rock; the action of metamorphism has an equally marked effect. When the heat has been moderate, the effect on the ore seems to consist simply in minor chemical changes in the character of the ore, often converting it from a soft, earthy material to a more compact, and sometimes crystalline ore; and frequently tending, by a process of solution and re-deposition, to free it from its insoluble impurities.

In the Coast Ranges of California, where the accompanying rock has been much altered by the conversion of shales into phthanite, or jasper, the manganese ore still remains in the state of oxide, without having formed to any extent other chemical combinations. The ores often contain considerable quantities of silica, and appear to be bedded deposits laid down at the same time as the enclosing rock. If, therefore, there had been sufficient heat during the metamorphism of the rocks, the well known affinity of manganese for silica under intense heat would have caused a part of it at least to go into the form of silicate. Different reasons are also adduced by Mr. Becker* to show that the metamorphism of the shales of the Coast Ranges was brought about at comparatively low temperatures. The same thing seems to hold true of the manganese deposits in the novaculite of

* Geology of the Quicksilver Deposits of the Pacific Coast, Monograph U. S. Geol. Survey, No. XIII., 1888, p. 138.

southwestern Arkansas: the ores there now exist as oxides, but if they had been subjected to a high heat the intimate relation of the ore with silica (novaculite) would doubtless have given rise to silicates.

When, however, the temperature is high, the silica and the oxide of manganese combine to form silicates of manganese. When other bases are present, complex silicates are often formed, containing manganese as one of their constituents. An action of this kind may have brought about the formation of the bedded deposits of various manganese-bearing garnets which occur in the quartzites, gneisses, and schists of Llano and Mason counties, Texas. In fact, the same cause probably also explains the comparative rarity of oxides of manganese and the very general presence of the different manganese-bearing silicates in other crystalline rocks.†

In the area of crystalline rocks of central Texas, beds of manganese-bearing silicates and of oxide of iron are often found in gneisses and schists in the same locality, and the silicate often contains minute grains of magnetic oxide of iron. (See page 433). In one place on Horse Mountain, five miles north of the town of Llano, in Llano county, Texas, a manganese-bearing silicate, probably a garnet, occurs in nests and pockets in a bed of magnetic iron ore. In other places also, not only in Texas but elsewhere, manganese in the form of silicate is a frequent associate of magnetic iron ores. Such occurrences show a much less stable condition under intense metamorphic influences for oxide of manganese than for oxide of iron; since, while the latter remains, partly at least, in the oxide state, the former combines with the silica present and goes into the form of silicate. This difference in action with silica would tend to make the ratio of the amount of manganese in the oxide form to that in the silicate form, in the

†It has already been stated that free oxides of manganese, where they occur in crystalline rocks, are often secondary products from the oxidation of silicates and other minerals, and that as original constituents of those rocks they are much rarer than the silicates. Free oxides of manganese do sometimes, however, seem to exist as original constituents of crystalline rocks. They occasionally occur in a pure state, at other times as manganiferous hematites and magnetites; or in such combinations as the mineral franklinite, an oxide of iron, zinc, and manganese.

metamorphic rocks, much smaller than the same ratio in the case of iron, and such is found to be the case.

The affinity of manganese for silica is well illustrated in the manufacture of spiegeleisen and ferro-manganese; here one of the principal difficulties is to prevent the manganese, during the smelting in the furnace, from combining with the silica. This tendency is partly overcome by using a highly basic slag, but other difficulties are met if the slag is too basic, and even with all precautions a loss of from 4 to over 15 per cent of manganese, varying according to the percentage of manganese in the product to be obtained from the furnace, is often sustained in reducing the ores to spiegeleisen or ferro-manganese. In this artificial combination of manganese and silica, a certain proportion of iron also enters, making a more or less complex silicate, in composition not unlike some of the native silicates.

THE ORIGIN OF THE MANGANESE DEPOSITS OF THE BATESVILLE REGION OF ARKANSAS.*

The manganese ores of the Batesville region of Arkansas originally occurred in lenticular layers, pockets, and flat concretions following in a general way the planes of stratification of the St. Clair limestone; they now exist in a similar form in the residual clay which has resulted from the decomposition of this limestone. The limestone is of an age intermediate between the Trenton and Niagara of the Silurian system. It lies almost horizontally over considerable areas, but dips with gentle monoclines to the south, finally disappearing under the Lower Carboniferous strata of the Boston Mountains. Ten miles to the north of where it appears from under the overlying rocks, it has been entirely removed by erosion, and the underlying Silurian limestones and sandstones comprise the country. To the east and west of the Batesville

* The discussion of the origin of the deposits of the Batesville region is taken up here instead of in the description of that region in previous chapters, as the subject is directly dependent on the conclusions concerning the chemical relations of manganese reached in this chapter. It is therefore most consistently treated in this place, and it also serves to illustrate certain principals in the formation of manganese deposits in general, which it has been the object of the present chapter to describe.

region it follows the general south-of-east and north-of-west strike of the rocks.

The Batesville region comprises a territory of about 122 square miles, in which manganese characterizes the limestone in local areas. In a similar manner, the region considered as a unit represents an isolated manganese-bearing area of the St. Clair limestone, blending both to the east and the west into a limestone of the same geologic age, but without any appreciable quantity of manganese. An analysis of the barren rock generally shows a fraction of a per cent of manganese such as exists in many limestones, but the nodules and larger bodies of ore are wanting. Isolated areas of manganese deposits have been reported in the St. Clair limestone to the northwest of the Batesville region, but their extent has not yet been proved. The Batesville region, therefore, represents an abnormal local accumulation of manganese in a formation which, though characterized throughout by a certain amount of that material, contains it elsewhere in only limited quantities. (For further details see chapter VIII.)

The St. Clair limestone in the Batesville region not only differs from the same rock elsewhere in its contents of manganese, but also in two other marked features: (1) its thickness and (2) its lithologic composition.

(1) The limestone reaches its maximum thickness of 155 feet in Penter's Bluff, in the western part of the Batesville region. To the east the limestone rapidly becomes thin, and in less than ten miles from the eastern border of the region, or twenty-five from Penter's Bluff, it is represented either by a stratum of only a few feet in thickness or else it disappears altogether. To the west it retains its full thickness for about eight or ten miles, and beyond that it becomes thin in the same manner as to the east, but less rapidly. In the manganese region the ore occurs in the limestone at various horizons from base to summit.

Immediately below the St. Clair limestone is the Izard limestone, which also reaches its maximum development (280 feet) on the western edge of the Batesville region, and

becomes thin to the east and the west in the same manner as the overlying formation.

(2) The part of the St. Clair limestone carrying the ore always contains more or less siliceous and argillaceous material, either finely disseminated through it or in beds of a sandy or shaly nature. Moreover the quantity of ore, in a general way, seems to vary with the quantity of earthy material: when there is a large quantity of the latter, there may be, though not necessarily, considerable deposits of manganese ore; while where there is little or no earthy material, there is usually but little manganese. This rule will not hold invariably, but in a general way it does, and an earthy nature is characteristic of the part of the limestone carrying the ore; while where ore is absent the limestone is often very pure and sometimes contains over 95 per cent of carbonate of lime. In some places the siliceous material is in the form of a brown or buff colored sandstone.

A microscopic examination made by Dr. J. E. Wolff of an earthy material containing flat concretions of manganese ore from the base of the St. Clair limestone in the Batesville region, showed numerous grains of detrital quartz with a few of feldspar and mica, cemented in an iron-stained calcite. Deposits which appear, macroscopically, to be of a similar material, are found in many other parts of the formation, though they have not yet been examined under the microscope. The nearest known source for such detrital fragments is the Archean area of Missouri, about ninety miles to the north, though at the time of the deposition of the St. Clair limestone, other Archean areas may have been exposed in closer proximity.

Any supposition, therefore, that will explain the origin of the Batesville manganese ores, must also explain the following phenomena:

(1) The localization of considerable deposits of manganese ore in a certain part of the St. Clair limestone.

(2) The fact that the St. Clair limestone reaches its maximum development approximately in the manganese [redacted]rea.

(3) The association of the ore with the quartz, feldspathic, and micaceous detritus.

The St. Clair limestone contains numerous fossils such as crinoids, corals, and other remains characteristic of a shallow water deposition. The occasional beds of sandstone in the limestone also lead to the belief that the deposition took place near shore; while the occurrence in an undecayed state, of such an easily decomposed mineral as feldspar, suggests that the distance from its source to its present resting-place was short. Moreover the comparative scarcity of these siliceous materials in the St. Clair limestone to the east and the west of the manganese region, points to the fact that these areas were either too far off shore to be reached by such sediments, or were outside the local currents that may have brought them.

Prof. Chamberlin, in his report already referred to,* gives a map showing the distribution of land and a probable system of oceanic currents in the Silurian sea which once covered a large part of the continent. The Archean area of Missouri is laid down as a series of small islands with the shoals characteristic of such an archipelago.† A current coming up from the south is divided by the archipelago and passes northward on either side. The present area of the Batesville region lay south of the "Missouri Archipelago," while the east and west extensions of the present area of the St. Clair limestone reached respectively to the southeast and the southwest of the islands. The Batesville region was in a position which might readily be subjected to a back-flow caused by the north-bound currents coming in contact with the islands. Under such conditions the back-flow would carry down earthy sediments from the land, and as the waters would probably move comparatively slowly or form eddies, the sediment would be laid down in this area with the calcareous materials from the sea, thus forming a more or less earthy limestone; while on either side of the back-flow, pure limestone,

* Geology of Wisconsin, 1873-79, Vol. I., plate XI.

† Small areas of crystalline rock which, at the time Prof. Chamberlin made his map, were commonly supposed to be Archean, are laid down in Arkansas. These have since been shown to be intrusive igneous masses.

either in the form of coral or calcareous sediments, might be laid down. The latter sediments would be free from earthy ingredients, and by their partial breaking up might readily supply a source of calcareous material in the area of the land sediments. The deposition of the earthy matter in the area in question required a condition of quiet waters, probably much in contrast with the more rapidly moving currents on either side. Hence the calcareous sediments from the sea water would also settle more easily and form a thicker deposit in the quiet area than in the currents.

This process would explain both the presence of siliceous and argillaceous sediments in the limestone in the Batesville region and the thickening of the limestone in the same area. The simple additional presence of earthy material would not alone be enough to account for the increased thickness of the limestone, but the facilities for the deposition of calcareous material would be ample cause for the accumulation of a greater thickness of limestone in this area than in the currents to the east and west.

This gradual local accumulation of land and marine sediments would eventually cause shoals and possibly coastal lagoons and swamps, into which the waters from the Archean rocks of the Missouri Archipelago would drain.

It has already been stated that all Archean rocks contain greater or less quantities of manganese, generally as silicates, carbonates, oxides, or other forms. The Archean rocks of Missouri are no exception to this rule, but on the contrary contain in some places more manganese than most Archean rocks. Professor Pumpelly * describes the occurrence of considerable quantities of manganese oxides in several places in the porphyry of the Archean area in the southeastern part of the state. The rock enclosing this ore is more or less decomposed, and sometimes the latter has weathered out and occurs in a red surface clay. The decay of the ore-bearing rocks by methods already described (pages 547–548) would afford a considerable quantity of man-

* Raphael Pumpelly, Geological Survey of Missouri, Iron Ores and Coal Fields, 1872, pp. 20-26.

ganese in solution in surface waters, and thus permit its transportation to the coastal shoals or lagoons. Here the solutions, exposed in a stationery condition to the oxidizing and evaporating action of the atmosphere, would deposit their metalliferous contents as carbonate or possibly oxide of manganese*. In some places considerable bodies of ore might be formed in one spot, in others the manganese would be disseminated through the mechanical sediments being laid down at the same time. A secondary chemical action might cause the segregation of the disseminated manganese and the formation of concretions of carbonate of manganese, which would be later oxidized in forms such as are characteristically shown at the Cason mine, near Batesville, and elsewhere in the region. In other places the manganese might remain in a finely disseminated state, causing the common occurrence now seen throughout the region of an earthy manganiferous limestone containing from 3 to 15 per cent of manganese.†

By these various local modifications of precipitation and segregation, the variety of deposits now seen, that is, flat layers of ore, nodules, concretions, and a finely disseminated coloring matter in the rock would be produced. The deposition would naturally tend to occur in certain spots more than elsewhere, the positions being regulated by the position of the swamps or lagoons, the various degrees of intensity of oxidizing agencies,

* The coastal lagoons or shoals in question probably contained considerable quantities of organic matter, and though a part of the ore may have been originally precipitated as oxide, the subsequent segregation of the ore in contact with this matter would probably finally deposit it largely in the form of carbonate. The ores as now found are in the form of oxides, and if the supposition that they were originally segregated as carbonate be true, the oxides must represent the product of the later oxidation of the carbonate, though some may represent the original form of deposition, as just stated.

† Professor Chamberlin (Geology of Wisconsin, 1873-9, Vol. IV., pp. 529-538) in discussing the origin of the lead ores of Wisconsin, which are associated with Silurian limestone supposes that they were derived from the Archean area forming the north shore of what is now the Lake Superior basin; that they were taken into solution and carried to the Silurian sea; that the configuration of the shore line was such as to deflect the oceanic currents which passed along this shore and cause them to cross what is now the southern part of Wisconsin Here, by the combination of currents, a gyratory motion was produced, with the resulting accumulation of seaweeds and animal remains, mostly the former. Largely through the medium of these material the lead in the current coming from the north shore was precipitated as sulphide. This ore was originally finely disseminated through the limestone and subsequently segregated. (For a further discussion of deposition as sulphides see pages 554—556 and 562—563 of the present report).

the possible presence of reducing agents, the depth of the water, etc., thus causing the characteristic feature of the Batesville region, that is, the existence of ore-bearing parts of the limestone separated by greater or less areas of barren rock.

A somewhat different explanation of the accumulation of the limestone and the ore might be given, but so far as the origin of the ore is concerned, the results would be the same: the St. Clair limestone may have represented a coral reef around a part of the Archean rocks; and in the quiet water between the reef and the shore, the siliceous and argillaceous sediments from the land and the calcareous detritus from the coral and other organic remains may have collected in the form of an earthy limestone. Such a mingling of land and marine sediments can be seen going on within many coral reefs at the present time, especially in the Feejee Islands* and elsewhere in the Pacific ocean, and it does not seem impossible that the same process may have taken place in the Silurian sea. This is rendered all the more possible by the character of some of the fossil remains in the limestone and by the fact that the warm southern currents, in which the region is supposed to have been situated (see page 589), were favorable to coral growth.

The intervening water area between the coral reef and the Archean island or islands would gradually become filled up, swamps would be formed, and the ore deposited in the way already described. The sediments within the reef being composed of both land and marine detritus, would form an earthy limestone, while on the outer parts of the reef, free from contamination by materials from the land, the coral and coral debris would form a comparatively pure limestone. This supposition of a coral reef would not only explain the local presence of earthy materials in the limestone and the formation of a basin suitable for the deposition of the manganese ore, but also the local thickening of the limestone, as it is characteristic of coral formations that they are thick in certain areas and rapidly thin out at their extremities. A similar explanation might also

* J. D. Dana, Corals and Coral Islands, third edition, 1890, p. 150–151.

account for the thinning out of the Izard limestone which underlies the St. Clair limestone.

A question that naturally arises in the discussion of the subject of the origin of the manganese deposits of the Batesville region is, what has become of the iron which must have been taken up in solution with the manganese in a district containing such large quantities of iron as the Archean area of Missouri? The manganese ore contains some iron, but not nearly so much as it should had all of both ores been deposited in one spot. The only answer to the question, therefore, is that the iron was separated from the manganese by methods already described (pages 569-573) and deposited elsewhere, and that possibly it has since been eroded. Iron ore is found just north of the Batesville region in a formation (Calciferous) older than the manganese-bearing (St. Clair) limestone, and it may have been derived at an earlier date than the manganese ore from the same source of supply in the Archean rocks of Missouri. The deposition of either ore depends on the fulfilment of certain conditions which are only locally realized, and one set of conditions will cause the precipitation of iron and not of manganese, while another set will precipitate both ores together; thus causing the occurrence in some places of one ore, elsewhere of the other, and in still other places of both together, as already explained in this chapter (pages 569–573).

Though the above explanation of the origin of the Batesville manganese ores accords with the facts observed in the region and seems well within the bounds of possibility, yet it cannot be stated with certainty to have taken place until further investigation has been made. An examination of the country between the manganese region and the Archean area of Missouri, a careful study of the latter area itself, as well as a further examination of the siliceous and argillaceous accompaniments of the ore in the Batesville region, will throw a great deal of light on the subject. The above statements have been made with the light of but a part of such information and are, therefore, offered only as suggestions which a more detailed investigation may either verify or not.

Before leaving the subject of the origin of the Batesville ores, mention should be made of what may prove to be an igneous material. This forms a layer from six to fifteen inches in thickness immediately above the St. Clair limestone. (See pages 127–128.) Dr. J. E. Wolff, of Harvard University, who has kindly made a microscopic examination of the material, has found evidence of its possible origin as a volcanic ash, though he points out the necessity of further investigation in the laboratory before the matter can be definitely settled. He describes it as composed of rather angular, small, clastic grains of quartz and of fragments of triclinic feldspar, often much bent and rounded, and sometimes angular; together with deep brown, homogeneous grains which are partially transparent, but completely isotropic in polarized light. The latter show neither cleavage nor crystal structure, and look like possible fragments of a ferruginous basaltic glass. The grains are separated by thin films of a green chloritic substance. This material has as yet been found in only one locality and has not been identified actually in the ore-bearing limestone, but the microscopic examinations so far made have been far too few to permit the statement that it does not exist, and possibly it may yet be found.

If further investigation proves the presence of this material within the ore-bearing limestone, another possible source of manganese will present itself. (See page 564.) The one exposure in question directly overlies a deposit of ore in the limestone, and might be thought to have had its influence as a source of the manganese by a replacement of the limestone. This, however, does not seem probable, and if the material has had any influence at all in the origin of the Batesville ore in general, it has been most likely by the oxidation of its manganese-bearing constituents and by the segregation of the manganese during the deposition of the limestone. Even this action cannot be stated to have gone on until the presence of similar materials can be proved at lower horizons in the limestone. The rock in question gives only a very faint reaction for manganese and could not have been instrumental in the formation of any considerable

deposits of ore unless it was in very large quantities, a possibility that is doubtful.

In conclusion, therefore, it may be stated that the evidence at present available points rather to the origin of the manganese ores from the decay of the Archean rocks of Missouri than from volcanic debris.

To summarize the conclusions arrived at: the Batesville ores were precipitated from surface waters draining southward from the Archean region of Missouri. The area of precipitation was originally a region of comparatively quiet water bounded on either side by rapidly flowing currents; this condition allowed the excessive accumulation of marine sediments and caused a greater thickness of the St. Clair limestone than to the east or west; the detritus from the land was carried down and mixed with the calcareous materials; the gradual accumulations of these mixed sediments caused shoals and then coastal lagoons and swamps into which the surface waters from the land emptied, and by a process of oxidation and evaporation deposited the metalliferous matter that they carried in solution.

Looking at the conditions of deposition of the ore in a somewhat different way, the St. Clair limestone may have represented a coral reef on the border of the Archean region, and in the quiet water between the two areas were gradually accumulated the calcareous sediments from the sea and the siliceous and argillaceous materials from the land, forming an earthy limestone in which the manganese was deposited in the same manner as that just mentioned.

SUMMARY AND GENERAL CONCLUSIONS.

The conclusions which have been reached in the present chapter may be briefly summarized and discussed as follows:

Sources of manganese.—The manganese found in the Paleozoic and later sedimentary strata has been supplied by the decay of the pre-Paleozoic rocks (Archean, etc.) and of the products of igneous action. The first class of rocks appears

to have been the more important source of supply for the metalliferous matter, though, as many of them are themselves composed of igneous materials, both sources of supply are intimately associated and the determination of the relative importance of either is in many cases doubtful. The supply of manganese in the pre-Paleozoic rocks was probably derived from still older rocks, though later metamorphism has converted the ores mostly into silicates; while the ores of the Paleozoic and later rocks are now mostly in the forms of oxides and carbonate.

The pre-Paleozoic rocks form a broken fringe around the Mississippi basin, and the most important deposits of manganese ore yet discovered in the United States are situated within it, or more rarely along its outer border. The deposits of New Brunswick and Nova Scotia are situated on the outer border of the main crystalline belt of the Appalachians, while the manganese belt of the Atlantic states is mostly on the inner side of the barrier.

The supply of manganese in the crystalline rocks exists mostly in the manganese-bearing silicates and the less common manganese carbonate and other minerals carrying manganese as a more or less important constituent. By the decomposition of these minerals the metallic oxides are freed from the various mineral-forming acids, silica, etc., and combine to form soluble compounds with the organic and inorganic acids which are active agents in the ordinary processes of rock decay. Intermediate stages of oxidation and reduction of the metallic bases usually occur between the time they are freed from the original mineral and when they combine with the other acids. The soluble compounds of manganese are taken up by surface waters and are eventually deposited where the conditions are suitable for their precipitation.

The decay of the crystalline rocks has progressed from the earliest times to which there are means of tracing it, and by its agency a source of supply of manganese has been continually contributed to the circulating waters. It is still progressing and, as in the beginning of Paleozoic times and ever since then,

the manganese in solution is precipitated and gradually forms deposits of ore wherever the necessary conditions are fulfilled.

The forms in which manganese is deposited.—At ordinary temperatures manganese is usually deposited in the oxide or carbonate form. Though many other metals are deposited as sulphide, there is strong evidence against the supposition that the sulphide of manganese has ever been the original form of any considerable deposits of ore of that metal laid down under ordinary surface conditions*. In this respect manganese differs from iron which is often deposited as sulphide in large beds. Manganese does not form any sedimentary deposit resembling the silicate of iron and potash known as glauconite. Consequently while iron at ordinary temperatures is deposited in four forms, oxide, carbonate, sulphide, and silicate, manganese under similar conditions is deposited in only two forms, oxide and carbonate.

Conditions of deposition of manganese.—As the manganese derived by the action of surface waters on crystalline rocks is in solution, it is redeposited only where these waters are exposed to conditions suitable to cause them to part with their metalliferous contents. These conditions are usually fulfilled when the waters are subjected to active oxidizing influences. The waters of many springs, therefore, deposit manganese oxide or carbonate in their discharge channels, and river waters frequently coat the pebbles in their course with a black incrustation of manganese oxide. Deposits of notable size, however, are formed only where the waters remain stationary for a sufficiently long time to permit the precipitation of a considerable portion of their metalliferous contents in one place. Such conditions exist in those bogs, lakes, coastal lagoons, or other local basins which are the receptacles of waters draining from areas of manganese-bearing rocks. Precipitation under these conditions, especially in coastal lagoons and shoals, has probably been the origin of most of the workable deposits of manganese ore in the United States.

In some places, however, there is evidence that the ore has been deposited on the sea floor, and precipitation of this kind is

* Small quantities of manganese sulphides are found in certain metalliferous veins and also under other circumstances (see pages 554-556), but the conditions considered here are those accompanying the formation of ordinary sedimentary rocks.

known to be in progress at the present time. The solution of manganese brought down from the land becomes greatly diluted in the sea water, and would not be readily precipitated by the simple action which brings about deposition from the much stronger solutions in local basins. It is necessary, therefore, to suppose in the case of deposition on the sea floor, either that there is some additional, powerful precipitating agent which can abstract from the water the minute quantities of manganese it holds in solution, or that there is in certain areas of the sea a local source of supply of manganese far greater than exists in others. With many metals such as iron, lead, and others a suitable precipitating agent is found in organic matter or soluble sulphides, which cause the deposition of sulphides of those metals; but there is evidence that manganese would not be precipitated as sulphide under many conditions which would reduce these other metals to that form. Moreover there is reason to think that manganese, under ordinary conditions of deposition, is always laid down as oxide or carbonate.

As no adequate agent can be found in the sea water that would precipitate the oxide or carbonate of manganese from the very dilute solution usually present, it becomes necessary to suppose a local source of supply of manganese in certain areas of the sea floor. Such a supply might exist either in solution or in a solid state. If in solution the difficulty of a precipitating agent is again met and it seems necessary to suppose a supply in the solid form. This might come partly as mechanically suspended particles of detrital silicate or oxide of manganese, which have escaped solution in surface waters, but it seems more probable that it was chiefly supplied by volcanic debris, such as has been suggested to be the source of the recent sea bottom nodules of oxide of manganese. Small quantities of manganese, however, may have been deposited on the sea floor by other processes already described on pages 559-564.

The deposition and segregation of manganese have been proved to be taking place on a notable scale on many sea bottoms at the present time. Moreover, in the rocks of past ages there are evidences of an open sea deposition of the ore: some of the

manganese ores in the Lower Carboniferous limestone of New Brunswick and Nova Scotia are believed to represent such a mode of formation, and the manganese deposits in the novaculite of southwestern Arkansas* were very likely deposited in an open sea. The nodules or pockets of manganese oxide found in many limestones, shales, and slates, as well as the carbonate of manganese found in various rocks, may also have had a similar origin. All these deposits, however, with the exception of those of Canada, are very limited, while in the case of the largest deposits of the United States there seem to be reasons for supposing that they were formed in shallow water and frequently in coastal lagoons or swamps. Some of the smaller deposits were formed in inland bogs or lakes. If a deposition of manganese like that now in progress on many sea bottoms, therefore, were prevalent in former geologic ages, it does not seem probable that, with the exception of some of the New Brunswick and Nova Scotia ores, it could have produced any extensive deposits.†

The three most important manganese-producing areas in North America are the Appalachian region from Vermont to Georgia, the Batesville region of Arkansas, and the New Brunswick and Nova Scotia region‡.

The Appalachian deposits are associated with iron ores which are supposed by J. D. Dana to have been formed in coastal lagoons. (See page 559.)

The Batesville deposits appear to have been derived from the Archean rocks of Missouri, and to have been laid down either in shallow sea water near shore or in coastal lagoons and swamps. (See pages 586–595.)

Some of the manganese deposits of New Brunswick and Nova Scotia are supposed to represent an open sea precipitation of ore. (See pages 567–568.) In certain localities, however,

* This region is not to be confounded with the manganese region of northern Arkansas, or the Batesville region.

† These remarks refer only to the deposits of the United States and Canada.

‡ Important quantities of manganese ore are obtained from the Leadville region, Colorado, but the ore of that district occurs under conditions entirely different from those under consideration. (See pages 462-463.)

such as at Loch Lomond in Cape Breton, the manganese-bearing limestone occupies basins which once represented small bays, surrounded by crystalline rocks, on the shores of the Carboniferous sea. It seems possible that in some of these places the manganese may have been deposited in shoals or coastal lagoons.

Association and separation of manganese and iron.—Manganese and iron are frequently found together in the same deposits, but they also occur separately. As both ores are derived from the same source, are taken up in solution together, and under many conditions are precipitated by the same influences, their frequent association in ore deposits is what would be expected. Under certain circumstances, however, iron and manganese may be precipitated separately, and hence the not uncommon occurrence of deposits of each in a state more or less free from the presence of the other. From the solution of manganese and iron the latter may be precipitated as oxide, and the manganese, on account of a difference in oxidability, may be precipitated afterwards as either oxide or carbonate. Under varying conditions this could cause either an intimate association of the two ores or an alternation of layers of each, or even a complete separation. Moreover, the iron might be abstracted from solution as sulphide, while the manganese, less capable of precipitation in this form, might be carried on and deposited as oxide or carbonate, thus again causing a separation of the two ores. By supposing the iron to have been sometimes laid down in sea water as glauconite, a manner in which manganese is not known to occur, an additional means of separation would be had. Thus by changing the forms and conditions of precipitation the various associations and separations of the two ores in nature may be explained.

Secondary chemical action in manganese deposits.—Since the time the manganese deposits were formed both they and the enclosing rock have undergone considerable alteration, and are now found mostly as oxides in a residual clay that has resulted from the decomposition, in situ, of the rock. Sometimes, however, the rock still exists in an undecayed state even on the surface, and between the condition of no decay and that of complete

decay there are all gradations. In some places the decay has extended downward for almost three hundred feet and in rarer cases probably considerably more. The acids derived from the oxidation of the ore during decomposition and the nature of the associated rocks have hastened the decay of the ore-bearing stratum, which has often been completely converted to residual clay, while the other rocks in the neighborhood exist in a comparatively little altered condition.

Where the original rock was horizontal or where it dipped at low angles, as in the Batesville region of Arkansas, the products of the decay of the ore-bearing stratum exist as isolated areas surrounded by areas of the underlying rocks; where the original rock dipped at high angles, as in the Appalachian region, the products of decay occupy well defined belts following certain topographic and geologic positions throughout the area of their occurrence; and, on account of the ease with which they are eroded as compared with the surrounding undecayed rocks, they are generally found in valleys or hollows.

Where the ore-bearing rock is exposed on the surface in an undecayed state, it is often in the form of a breccia cemented by manganese oxide, an occurrence usually caused by secondary chemical action in the deposit subsequently to its deposition.

Metamorphism at low temperatures has but little effect on manganese deposits except in some cases to cause minor chemical changes in the condition of the ore. Metamorphism at high temperatures, however, has a very marked effect, frequently converting the original oxides or carbonate into silicates. Manganese appears to combine with silica during metamorphism much more readily than does iron, and the ratio of the percentage of silicate of manganese as compared with that of oxide of manganese in metamorphic rocks is therefore much greater than the same ratio in the case of iron.

The ores of manganese.—As already stated the common forms in which manganese is deposited are oxides and carbonate. The carbonate is readily decomposed and converted to oxide by exposure, so that now almost all the workable manganese deposits in the Paleozoic and later rocks exist in

the form of oxides. Frequently, however, limited quantities of carbonate of manganese still occur in rocks of various ages. Such deposits usually show on the surface a greater or less quantity of oxide which has been derived from the partial decomposition of the carbonate, and they doubtless represent the former condition of many manganese deposits now found in the oxide state. Carbonate ores are found at Placentia Bay, Newfoundland; in western Massachusetts and eastern New York; in the spathic iron ores of Pennsylvania; and in other places mentioned on pages 553 and 554. In the pre-Paleozoic rocks most of the manganese ores have been converted to silicates by metamorphism, though the carbonate and oxides sometimes occur. The last two, however, have in many cases been derived from the alteration of the silicates. (See page 545.)

THE GEOLOGIC DISTRIBUTION OF MANGANESE*.

As a result of the processes of formation already described, manganese deposits are not confined to any certain geologic horizons, but occur in greater or less quantities in many rocks from Archean to Recent.

Pre-Paleozoic deposits.—The oldest known manganese deposits are in pre-Paleozoic rocks, where they exist mostly as silicates and to a lesser extent as carbonates and oxides. The silicates of manganese in the crystalline rocks of the Appalachian region from Maine to Georgia, the oxides of manganese in the porphyry of southeastern Missouri, and the manganese-bearing garnets and other silicates in the central Texas region represent pre-Paleozoic deposits. With the exception, however, of limited quantities of ore from Missouri; northern Michigan; Blue Hill, Maine; and a few other places, rocks of pre-Paleozoic age have not supplied any important part of the production of manganese ores in the United States.

Cambrian deposits. — The oldest deposits which have

* The following remarks concerning the geologic distribution of manganese are intended to apply only to the deposits of the United States and Canada, and not to other foreign deposits.

afforded commercially important quantities of manganese ore in the United States are of Cambrian age. These occur in and overlying the sandstone or quartzite of the eastern side of the Appalachian Valley. The exact geologic position of all the deposits of this belt is somewhat uncertain: some have been proved to be of Lower Cambrian age, others have not been determined and may be Silurian, though no direct evidence yet exists that they are not Cambrian. (See pages 376-380.)

This belt, whether of Cambrian or later age, has been the most productive in America and has afforded probably over three fourths of the manganese ore mined in the United States. (See page 65.) It includes some of the deposits of Vermont; the deposits at the Crimora, Lyndhurst, Cabell, Bagley, and other mines in Virginia; the deposits of Shady Valley, Tennessee; Warm Springs, North Carolina; and the Cartersville region of Georgia.

The manganese deposits at Tête à Gauche Falls, New Brunswick, are in slates supposed to be of Cambro-Silurian age. (See page 515.)

Silurian deposits. — The lowermost Silurian manganese deposits yet determined in the United States are those of the Cave Spring region of Georgia. They occur in the Knox dolomite of Safford, which represents the base of the Silurian section in Georgia. A few hundred tons would comprise all the manganese ore that has been mined in this region.

Above the Knox dolomite manganese has been found in limited quantities in various Silurian horizons in the Appalachian region, but rocks known to be of such age have thus far afforded only small quantities of ore in this belt.

The manganese deposits of southwestern Arkansas, in the region from Little Rock to Indian Territory, are probably of Lower Silurian age, possibly Trenton. They do not contain ore in commercially important quantities and about thirty tons only have been mined.

The manganese deposits in the St. Clair limestone of the Batesville region of northern Arkansas occupy a position

between the Trenton and the Niagara groups, that is, they are intermediate between the Lower and Upper Silurian. Next to the Appalachian belt mentioned under Cambrian deposits, this region has produced more manganese than any other in the United States, its total output being between 30,000 and 35,000 tons, or probably between a sixth and a seventh of the total production of this country.

The manganese carbonate found at Placentia Bay, Newfoundland, is in slates supposed to be of Silurian age. (See page 530.)

Devonian deposits.—No commercially important quantities of manganese ore have yet been mined in the United States or Canada in rocks known to be of Devonian age, though certain quantities of ore are said to occur in rocks of this age in Virginia.

Carboniferous deposits.—The principal manganese deposits of New Brunswick and Nova Scotia are in Lower Carboniferous limestone. These include the Markhamville, Tenny Cape, Cheverie, Loch Lomond, and many other mines, and have produced almost all the manganese ore mined in Canada.

A deposition of manganese in Carboniferous times is also represented by the spathic iron ores of the Coal Measures of Pennsylvania and elsewhere, which often contain manganese; and also by the small quantities of manganese in other Carboniferous rocks in many parts of America.

The Canadian (New Brunswick and Nova Scotia) deposits have probably produced something under 50,000 tons of manganese ore, but, with the exception of this region, the Carboniferous rocks have not afforded any commercially important quantities of manganese ore either in the United States or Canada. *

Triassic and Jurassic deposits.—No important deposits of manganese have been found in the United States or Canada in rocks of Triassic or Jurassic age. Small quantities of ore,

* Important quantities of manganese ore are obtained from the silver deposits of Leadville, which are in Lower Carboniferous rocks, but these deposits were produced after the formation of the enclosing rock. (See pages 462-463.)

generally of low grade, have been found in Triassic beds (New Red Sandstone) in New Brunswick and Nova Scotia, and have already been mentioned in this report at Quaco Head, Cornwallis, and Wolfville (see pages 513 and 525), but the ore has been put to but little practical use. The Triassic rocks (Star Peak Triassic) of northern Nevada (see pages 473 and 476) give a reaction for manganese when tested chemically, and probably a similar reaction could be obtained from many other rocks of both Triassic and Jurassic ages, but manganese has not been found in them in quantities.

Cretaceous deposits.—The manganese deposits in the jasper, or phthanite, of the Coast Ranges of California are of Cretaceous age, and include the Old Ladd mine, Red Rock, the Saucelito openings, the Little Stony claims, and many other localities on the Pacific Coast of that state. These deposits have probably supplied about 10,000 tons of ore, though this is only a rough estimate and the quantity may be somewhat more or less. With the exception of the deposits of the Coast Ranges no commercially important quantities of manganese ore have been found in the Cretaceous rocks of either the United States or Canada.

Tertiary deposits.—Small deposits of manganese and manganiferous iron are said to occur in the Tertiary area of the Atlantic seaboard, but they are of limited extent and have produced but little ore. One of these localities near City Point, Virginia, is described in this report. The manganese deposit at Brandon, Vermont, is associated with Tertiary lignites in clay beds which have probably been formed of materials derived from an underlying Paleozoic deposit and rearranged in Tertiary times. (See pages 397-398 and 575-576.) The surface outcrops of many other Paleozoic manganese deposits may also represent a rearrangement of materials before, during, or after Tertiary times.

The City Point locality is said to have afforded a few hundred tons of manganese ore; the amount mined at Brandon is uncertain, though this locality has produced many times as much as the City Point deposit.

Pleistocene deposits.—The manganese deposit near Golconda, Nevada, is of Pleistocene age. It occupies a position in a calcareous lithoid tufa formed from solution during the desiccation of the extinct Lake Lahontan. Thirteen and a quarter tons of ore are said to have been shipped from this locality.

Probably some of the deposits of wad (bog manganese) found in the areas of crystalline rocks of the northern states and Canada represent Pleistocene deposits, but they have been put to only limited commercial use.

Recent deposits.—In late ages the deposition of manganese has been active, and even at the present time it may be seen progressing. The most noticeable instance of modern deposition is the formation of manganese nodules on many sea floors; and less striking but equally significant is the formation of deposits of bog ore now seen in many low places, especially in areas of crystalline rocks and to a lesser degree in areas of other rocks. (See pages 82-83, 501 and 548.) Many of the bog manganese ores of the northern states and Canada are recent deposits, and the gravels cemented by manganese in many canyons of the Rocky Mountains and elsewhere represent a similar formation. The bog ore in McHenry Creek, Pulaski county, Arkansas, is also a recent deposit, and the deposition of manganese at the mouths of many springs and on the pebbles of rivers also represents a modern precipitation. (See pages 550-554.)

Such deposits, however, have not proved to be of any value as a source of manganese, though limited quantities of bog ore have been consumed in the manufacture of paint.

Conclusion.—It will thus be observed that the production of manganese in the United States has been confined almost entirely to Cambrian and Silurian rocks (the Appalachian and the Batesville regions); with small quantities from strata of Cretaceous age (Coast Ranges of California), and of Tertiary age (coastal area of Virginia and Brandon, Vermont) and an insignificant amount from Pleistocene deposits (Golconda, Nevada). On the other hand, the production of Canada has been derived almost exclusively from Lower Carboniferous rocks (New Brunswick and Nova Scotia).

Hence, though manganese occurs in rocks of almost all, if not all, geologic ages, it is in very irregular quantities, sometimes occurring simply as a trace, at other times in deposits of large extent. Certain horizons may be characterized almost throughout by noticeable quantities of manganese, while other horizons may be equally marked by the rarity of this ingredient, or, as in most cases, may contain it in some places and not in others.

The source of manganese from crystalline rocks (pre-Paleozoic and igneous) is always present and has from the earliest Paleozoic times, and probably before, afforded a constant supply to the circulating waters. The variability in the quantity of ore in different horizons and in different places in the same horizon, therefore, must be accounted for by the conditions surrounding depositions in different ages. It is probably due to two causes which doubtless varied in their influence in different geologic ages and in different places. They are: (1) the extent of the exposed area of crystalline rocks; (2) the facilities for the deposition of the ore.

(1) In different geologic ages a change in the supply of manganese may have been caused by a difference in the area of crystalline rocks exposed to decay, and hence capable of supplying manganese to surface waters. Thus in early Paleozoic times a larger area of crystalline rocks was presumably exposed than in later times, and, therefore, the supply of manganese must have been larger than when these rocks were more or less covered by clastic rocks. Moreover, in certain ages volcanic action has doubtless been more active than in others, and as the materials produced by this action are sometimes an important source of supply of manganese, the deposits of ore of this metal have probably sometimes been influenced by the greater or less abundance of such materials. (See page 543 and 564.)

It might be said that younger strata had a source of supply of manganese in the older clastic rocks which had already derived a certain amount of manganese from the crystalline rocks. To some extent this is true, but for reasons given on page 573 the crystalline rocks are by far the more ready source of man-

ganese for sedimentary deposits; and, if other things were equal, the amount of that material supplied to circulating waters would depend largely on the area of crystalline rocks exposed.

(2) If the influence just mentioned, that is, the extent of the area of the crystalline rocks exposed, had been the only one affecting the formation of manganese deposits, the problem would be a simple one; but, though the ore is dependent on the crystalline rocks for its presence in later sediments, yet the varying facilities for the deposition of the ore have probably played a far more important part in the localization of the deposits than has the difference in the exposed area of crystalline rocks. In all geologic ages there have probably been sufficient areas of crystalline rocks in process of decay to supply a source of manganese, but it is only when certain sets of conditions are fully realized that the ore is deposited in appreciable quantities, while elsewhere it remains in solution. As a result, the waters of a certain area may receive a large quantity of manganese and form no deposits; while in another place where the conditions are suitable, waters receiving much less manganese may form large deposits. For example, if the metalliferous solutions drained into an open sea an immense amount of manganese could be retained without allowing any precipitation; while if much less strong solutions drained into bogs or coastal lagoons, where they would be exposed to active oxidation, sometimes assisted by evaporation, the conditions would be fulfilled for the formation of extensive deposits of manganese ore.

It is evident, therefore, that, though the presence of manganese in formations of various ages is largely due primarily to a source in the older rocks, the variations in its geologic distribution, and in its geographic distribution in a given geologic formation, are dependent almost entirely on local conditions of deposition.

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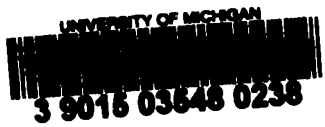
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